THE HOW AND WHY OF ELECTRICITY

A BOOK OF INFORMATION FOR NON-TECHNICAL READERS

BY

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PREFACE

It is not the purpose of this book to tell what electricity is, for the writer does not know, but to tell something of its properties, of how it is generated, handled, controlled, measured, and set to work, and to explain how familiar electrical apparatus operates. If this object is attained, or if it makes plain to anybody who wishes to know about these things, the points concerning which he seeks information, it will have accomplished its purpose.

C. T. C.

CHAPTER I

THE ELECTRIC CURRENT

It is not definitely known what electricity is. At various times it has been thought to be a form of matter, a thin, weightless fluid, a kind of force, a variety of motion, and a disturbance in the ether (which is supposed to fill all space, including the pores in even the most solid metals). With these speculations, this book has nothing to do. For its purposes we may conceive electricity to be a fluid having peculiar properties and subject to certain simple and invariable laws. We may conceive of this fluid as without weight, capable of almost inconceivably swift motion, manifesting itself at certain places and under certain conditions as light or heat, and elsewhere as magnetism, or as an influence to bring about chemical action. We may also conceive that we live surrounded by it and that it becomes evident to us only when it is in motion, or when the amount of it present in any given object is more or less than the average amount. With these premises we are ready to examine into the methods in use for setting it in motion, and putting it to work.

A few definitions are needed at the outset to make matters clear. All substances permit electricity to flow through them in some degree—some almost wholly opposing its passage, and others allowing it to move with the greatest freedom; while between these two extremes lie a great number of bodies of intermediate properties. Those through which the fluid can pass freely are called

conductors; those which obstruct its passage are called non-conductors, or insulators. The properties of both are inherent qualities of the substances themselves, though varying with their physical condition—their temperatures, for example.

Silver is the best conductor, copper being very nearly as good. The latter metal is used in enormous quantities for conducting wires and cables. All the metals and their alloys are conductors. Iron and steel conduct fairly well, but only about one-seventh as well as copper. Carbon, such as graphite and pure charcoal, is a very poor conductor, although in some special forms it is made use of as a conductor, as in electric batteries, in telephone protective devices, and in many processes of electrolytic decomposition. Solutions of metallic salts are intermediate conductors.

All gases, including air, are practically absolute non-conductors. So are oils and resins, glass, and, in general, all transparent solid bodies such as crystals and gems, porcelain, clay, wood and leather (when dry), india rubber and gutta-percha. Paraffine, ozokerite, or mineral wax, asphaltum and pitch are very perfect insulators, and are much used for covering wires. Paper and fibrous materials, such as silk and cotton, are also insulators.

If a conducting body is supported by an insulator, so that it is in contact with nothing else except the air surrounding it (also a highly perfect insulator), it may be "electrified." That is, it may have electricity added to its normal charge of the electrical fluid or have it taken away, much as one might pour a liquid into or out of a bottle. Such a conductor on its insulated stand is shown in Fig. 1, which represents a metallic ball supported by a

glass rod. When it is electrified its appearance is in no way changed, but it has been endowed with a number of new properties. It can attract other objects. If it is connected with the earth, the general reservoir of electricity, by a wire, electricity will rush in or out of it, ac-

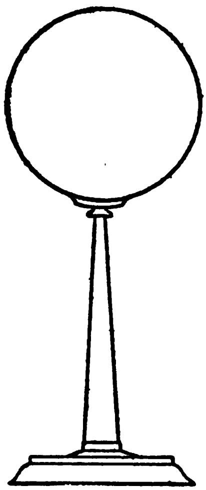

FIG. 1

cording to whether its electrical condition is due to a deficiency or an excess of charge, until equilibrium is established. This rush of electricity along the wire is an electric current, and the phenomena of such currents include practically all the useful applications of electricity.

CHAPTER II

THE ELECTRIC BATTERY

It was discovered more than a century ago, by Alessandro Volta, that the process of dissolving a metal in an acid caused a difference of pressure of the electric fluid in the acid and the metal, and that with appropriate apparatus this difference of pressure could be made to cause a constant flow of electricity along a wire. Such an apparatus in its simplest form is shown in Fig. 2. Here, in a suitable vessel, of glass, or hard rubber, or some other substance not attacked by the acid, is a quantity of sulphuric, hydrochloric, or any other acid, and in this two pieces of metal. One of these is zinc or

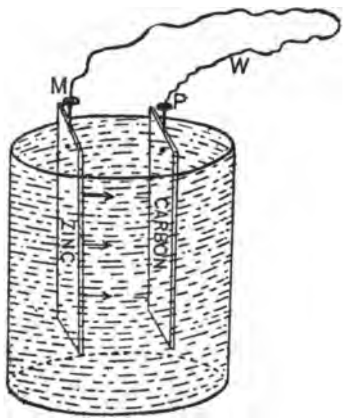

FIG. 2

iron or some other metal which the acid will attack and dissolve; the other is platinum or carbon (not a metal), or some other conducting substance which the acid does not act upon, and which is immersed in the liquid simply to enable a convenient connection to be made by the wire W. If, now, the two wires are joined together, a current of electricity will flow from the acid by means of the plate P, and through the wire to the plate M, which is being attacked by the acid. This current will continue to flow as long as there is any chemical action going on, or until the plate M is all dissolved, or the acid all neutralized by its solution. Such a contrivance is called an electric battery.

Batteries are made in a number of varieties for furnishing small currents for telegraphing and telephoning, for working door-bells, signals, sparkers, and other purposes not requiring large amounts of current. In most of them zinc is the metal dissolved, and a carbon plate, or cylinder—made by pressing a paste of petroleum, coke and tar in molds and heating it white hot—is used to make connection with the acid fluid. It is not necessary to use a free acid, which is a dangerous liquid to handle, and much use is made of such salts as sal ammoniac (chloride of ammonia) and sulphate of copper in batteries. Some batteries use caustic alkalis instead of acids to dissolve the zinc, the principle of operation being the same. The different substances, which make up a completed battery, are known in practice as "elements." In the common form of battery the carbon element is termed "positive," the zinc element being termed "negative."

If the zinc is made in the form of a cup or cylinder and the carbon supported within, the fluid being mixed

with gelatine so that it forms a stiff jelly, the cell may be sealed up with paraffine or asphalt to form the convenient "dry battery," of which several millions are manufactured annually.

Storage or secondary batteries are described in a later chapter.

To all intents and purposes a battery may be looked upon as an electricity pump. It circulates the fluid through any conducting path to which it is connected, consuming zinc and acid to furnish the needed energy to keep up the flow. Let us now look at the phenomena that take place in and around this conducting path when the current is flowing in it.

CHAPTER III

THE EFFECTS OF ELECTRIC FLOW IN THE CIRCUIT—HEAT AND CHEMICAL ACTION

If we measure the temperature of the conducting circuit, we will find that it grows warmer when the current flows in it. The amount of heat developed depends upon the nature of the conducting wire and its size. Every path through which electricity flows offers some obstruction to the flow. This quality is known as *resistance,* and is an important property of a circuit. The resistance of a definite length of wire of a given diameter and of a given material is a perfectly definite quantity and may easily be measured. It is expressed in units called *ohms,* after the name of Dr. Georg F. Ohm, a German scientist who discovered the law of electrical flow. An ohm is equivalent to the resistance of 251 feet of No. 18 gauge copper wire, which is about the size of the iron wire used in making hair pins. A steel wire of the same size and length would have a resistance of about seven ohms. An ordinary pencil lead (which is a poor conductor) has about 10,000 ohms resistance.

The heat developed in a conductor with a given amount of current flowing through it depends upon the resistance. If one part of the circuit has a higher resistance than another, more heat will be developed there. If in a circuit of large copper wire a small piece of fine iron or platinum wire, having relatively a very large resistance, is introduced, a current which will barely warm the copper wire will heat the iron or platinum

white hot. This arrangement is used for exploding mines and blasts and in warfare for exploding submarine torpedoes. A short piece of very fine platinum wire is fastened between the ends of two stout copper wires and sealed up in a small cartridge of fulminating powder to make the detonating caps used in dynamite blasting. A very familiar evidence of this phenomenon is the incandescent lamp.

Heat is developed everywhere in the circuit by the flow of electric current. If the circuit is broken, a bright spark is noticed. This is due to the sudden heating of the last particles of metal in contact, and possibly to the heating of an infinitesimal puff of metallic vapors formed by the volatilization of the metal. Here we have both heat and light produced by the action of the current.

If the circuit is led through a conducting liquid, such as a solution of copper sulphate, another effect is produced. If two iron or carbon points are used to lead the current into and out of the solution, one of them will soon be seen to be covered with a bright coating of metallic copper. If copper points are used, the one by which the current enters the solution will waste away, while the other will increase in size, the solution remaining unchanged. These phenomena are the basis of the arts of electroplating and electrotyping. Many metals, such as copper, nickel, silver and gold, can be deposited or plated from solutions of their salts by means of the electric current. In every case the deposited metal is plated upon the object through which the current leaves the solution; in other words, the metal always travels with the current, being dissolved off the plate by which the current enters and deposited on that

by which it leaves the bath. In practice these plates or objects are called anode and cathode respectively.

If the current is led by a suitable anode and cathode through water, gases are seen to bubble up at the plates. These are the constituent elements of the water, hydrogen and oxygen, the current thus decomposing the water.

The effects of a current in its circuit are thus seen to be of two kinds, thermal and chemical.

CHAPTER IV

THE EFFECTS OF ELECTRIC FLOW OUTSIDE THE CIRCUIT — MAGNETISM AND INDUCTION — THE ELECTRICAL UNITS

Outside of the circuit wires other effects of great importance are produced. If the current carrying wire is held parallel with a compass needle the needle deflects to east or west, in accordance with the direction of the current. If the wire is wound around a piece of iron the latter becomes strongly magnetized when the current passes. If the wire is laid parallel with another wire, but entirely insulated from it, momentary currents will flow in the latter at the instants of starting and stopping the current in the first wire. These momentary currents flow in opposite directions, that arising from the closing of the first circuit (the starting of current flow in it) being in the opposite direction to that current, while the momentary pulse of current due to opening the circuit, or stopping the flow, is in the same direction as the original flow. These phenomena are known as electromagnetic induction.

Conversely, if the wire carrying the current is arranged so that it can move freely, upon presenting the pole of a magnet to it, it will move, tending to revolve about the magnet. Upon these relative actions of currents and magnets depend most of the larger applications of electricity in the arts.

It will be convenient here to speak of the units in which electric currents are measured. These units are

exactly similar to those used in measuring water or gas flowing in pipes, and refer respectively to pressure and rate of flow.

The unit of electrical pressure is the *volt*, named after Allessandro Volta. We have seen that a battery is an electricity pump. The ordinary "bluestone" battery used in telegraph offices gives a pressure of almost exactly one volt.

The unit of current flow, corresponding to "gallons per minute" in water measurement, is the *ampere*, named after Jean Marie Francois Ampere, a French *savant*, who discovered many fundamental laws of electricity.

The ampere, volt and ohm are related by the simple law, first laid down by Dr. G. F. Ohm and bearing his name, as follows:

In any circuit the rate of current flow in amperes is equal to the applied pressure, in volts, divided by the resistance in ohms.

Thus, in a circuit of 4 ohms resistance a pressure of 10 volts will cause a flow of $\frac{10}{4}$ or $2\frac{1}{2}$ amperes. Pressure is often spoken of as "electromotive force," generally written "E. M. F."

The *power* of a current is measured not only by the rate of its flow, but also by the pressure or electromotive force through which it works; by the volume of flow and the head or pressure, as in measuring the power of a waterfall. The power of a current is measured in *watts* (named after the famous engineer, James Watt), and the number of watts of power exhibited by a given current may be found by multiplying the number of amperes flowing by the number of volts pressure under which they flow. Thus, in a circuit wherein 3 amperes are

flowing under 110 volts pressure, the power developed is 330 watts. In practice a larger unit, the kilowatt, equal to 1,000 watts, is generally used. One horsepower is equivalent to 746 watts, so a kilowatt is approximately 1⅓ horsepower.

CHAPTER V

ELECTROMAGNETS—THE TELEGRAPH

Many very important uses of electricity depend upon the power of the current to engender magnetism whenever it flows spirally around an iron or steel core. Such a core wrapped with wire is called an electromagnet. The core is made of soft wrought iron and may be made powerfully magnetic when the current flows, instantly losing its magnetism when the current flow ceases. Upon this property of the electromagnet depends the working

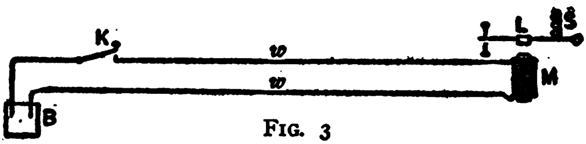

FIG. 3

of electric bells and alarms, the telegraph, and many other important varieties of apparatus.

The telegraph is one of the simplest applications of electricity. In Fig. 3 is shown a diagram of a simple telegraph circuit. It consists of a battery, B, and an apparatus for opening and closing the circuit, called a key, K, at the sending end of the line, two wires, *w w*, connecting the sending and receiving stations, and the receiving apparatus. The latter is simply an electromagnet, M, and a small bit of soft iron mounted on a lever, L, which is free to move between two stops. A spring, S, holds the lever away from the electromagnet.

If, now, the key is pressed down so as to close the circuit, the current will flow, the electromagnet will attract the bit of iron and the lever will be pulled down toward

the electromagnet so that its end will strike one of the stops and produce an audible click. When the key is released and the circuit broken, the electromagnet ceases to attract the iron and the spring pulls the lever back into its original position, making what telegraph operators call the "return click." These clicks, with the longer or shorter intervals between

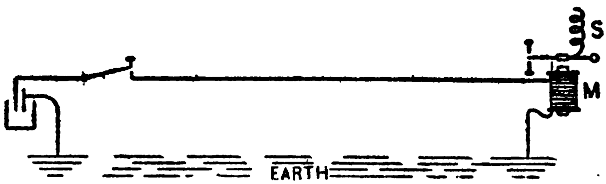

Fig. 4

them, form a code of signals representing letters and figures which the operators interpret into words and messages.

In practice it has been found that the earth itself is a very fair conductor. Consequently the arrangement shown in Fig. 4 is used. One of the two wires shown in Fig. 3 is suppressed, plates buried in the earth or water or gas pipes being used to secure a good electrical connection with the ground at each station.

The earth may be supposed to act as a conductor between the two places, or simply as a vast reservoir of electricity, from which the battery pumps out a little at one station, sends it over the line and restores it at the other. Perhaps the latter explanation is more nearly a true statement of the facts of the case.

On long telegraph lines the resistance of the wire employed is considerable and the amount of current (amperes) that the battery can pump through is insufficient to cause a loud click at the receiver. An instrument

known as a relay is employed to re-enforce the energy of the clicks. It consists of an apparatus exactly similar to the ordinary receiver illustrated in Figs. 3 and 4, but made with a very delicately adjusted lever. The stop for the lever is made like the sending key, and the movements of the lever are used to make and break the circuit of another battery at the receiving station, called the "local battery." In this local circuit is placed the magnet of a loud-clicking receiver or "sounder." The arrangement is shown in diagram in Fig. 5. It will be

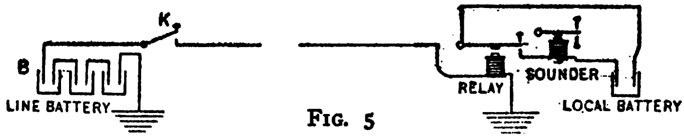

FIG. 5

noticed that several cells or jars of battery are shown at the sending station in this illustration. This arrangement is used where the electrical pressure or voltage from one cell is insufficient to cause enough flow of current for the purpose in hand through the necessary resistance of the circuit. In former days, collections of great numbers of cells of batteries were located in some telegraph offices, as many as 500 cells being used sometimes to work lines several hundred miles in length. To-day, the current used in telegraphy is generally generated by dynamo machines, which will be described in a subsequent chapter.

The sending and receiving instruments are duplicated at the two ends of a line, and at any intermediate station it may pass through, so that any station may send or receive. The usual speed of hand telegraphy (in which the sending key is worked by the operator's hand)

is about thirty words a minute. By punching a ribbon of paper with holes corresponding to the long and short signals of manual telegraphy the contact closing and opening key of a special sending machine can be worked at enormous speeds. The resulting clicks are then too rapid to be intelligible to the ear, so the lever of the receiving instrument is made to register its movements on another paper ribbon. By this system several operators at each terminal can be busied with punching sending tapes or translating the received ones, while a great volume of business can be conducted over a single wire.

By arrangements not necessary to describe here several messages may be sent and received simultaneously over the same circuit. Duplex and quadruplex telegraphy, whereby two or four messages are thus sent on the same circuit, are much used for commercial and newspaper business.

The ordinary telegraph line consists of galvanized iron or steel wire, sometimes copper wire, supported by glass insulators on wooden poles. The insulators are threaded and screwed on wooden pins, their bottoms being flared out into bell shape so as to keep rain water from forming a continuous film over the insulator, pin, cross-arm and pole, thus affording a conducting path to the ground over which the current might flow and be thus diverted from its proper channel. Where lines pass through cities they are generally run in cables. Cables for this purpose consist almost always of a number of copper wires, each insulated throughout its length by a wrapping of fibrous paper soaked in paraffine, and by india-rubber or some compound of it; the bundle of wires thus insulated being covered by a lead sheathing to keep out dirt and moisture and protect the insulation

and wires from mechanical injury. Each wire of the cable is generally part of an individual circuit.

When a telegraph line is to be laid under water, a cable of special construction is used. For long cables, gutta-percha is the only satisfactory insulating material, though rubber compounds have worked admirably up to two or three hundred miles. The conducting core is usually made of a number of fine copper wires lightly twisted together, this arrangement giving great flexibility and reducing the danger of breakage of the conductor. Over this is applied, by special machinery, a waterproof and seamless insulating covering of gutta-percha, generally about a quarter of an inch in thickness. Outside of this is laid a wrapping of tarrred hemp to protect the core, and outside of the hemp a layer of steel wires is applied. These are given a twist of about one complete turn in two feet. Their object is purely mechanical, to protect the core from the abrasion of the sea bottom and the appliances used in handling and laying the cable, and to give it strength to support its own weight when hanging from the ship in great depths of water. Those parts of deep-sea cables which are near the shore are much more heavily armored with steel wires than the mid-sea parts, being more exposed to waves, currents and icebergs, and the dangers of fouling with ships' anchors.

Short cables are worked precisely in the same way as any other telegraph lines. Long cables require special apparatus for the sending and reception of signals for reasons that will be more fully explained in a later chapter.

CHAPTER VI

ELECTRIC SIGNALING APPARATUS

A large variety of electric signaling apparatus, such as fire and burglar alarms, electric bells and annunciators, and the like, are really telegraphs. The ordinary messenger call boxes and fire alarm boxes are examples of what are called closed circuit telegraphs. In both these kinds of boxes the movement of a lever causes a short train of clockwork to turn a notched disk of metal upon the edge of which a spring lightly bears. This contact, between the disk and spring, is included in the circuit with a battery, a registering telegraph instrument and an alarm bell worked by an electromagnet. When the box is "pulled" the disk rotates. Every time a notch passes the spring the electrical contact is broken and the circuit is opened, causing all the electromagnets in the registering instrument and the bell to lose their magnetism momentarily and release their pull upon their iron armatures. These are moved by springs, in the one case, so as to actuate a pencil point or stylus and mark a record of the signals; in the other, so as to ring a bell. The notches in the disks are spaced so as to send in groups of signals, thus . . . . . . which would read as "321." A large number of boxes can be installed on one circuit, each having a different notch arrangement and sending in a different number. The closed circuit arrangement, by which current is always flowing, except when momentarily interrupted to give the signals, is specially advantageous for alarm boxes, as a

broken line wire or exhausted battery immediately sends in its own warning. The majority of burglar alarms are also constructed on this principle, a cut wire serving to send in the alarm signal.

Another variety of fire alarm signals depends on the heat of an incipient fire to give the signal through apparatus called thermostats. These depend for their working on the expansion of metals by heat. If a flat strip of brass and a similar strip of iron are riveted together, back to back, so to speak, the unequal expansions of the two metals will cause the compound strip to bend when it is warmed. Such a strip is arranged so that a given degree of heat causes it to bend itself into contact with a fixed point, closing an electrical circuit and sending in an alarm. A similar strip is used sometimes to regulate the temperature of rooms heated by hot air or steam heat furnaces. At the proper temperature the free end of the strip stands between two contact points. If the room becomes too warm or too cold it moves to one side or the other, thus regulating the furnace drafts by properly connected electromagnets. A very ingenious thermostat cable has recently been introduced. It consists of a core of copper wire surrounded by a sheath of a very easily melted alloy of lead and other metals. Outside of this is a loose wrapping of cotton containing in pulverized form a fluxing substance (also an insulator), while outside of the cotton wrapping is a spiral of wires. These wires and the core are normally insulated from one another, but if any part of the cable is heated the fusible alloy melts, the flux assists the melted metal to permeate the cotton, and an electrical contact is set up between the outer and inner wires. An alarm bell in circuit with these wires and a bat-

tery will thus ring if the cable is heated anywhere. These cables are laid about through the merchandise in a ship's hold, for example, or in a warehouse, and furnish a prompt alarm in case of fire.

The ordinary electric bell, of the vibrating variety, is shown in diagram in Fig. 6. The hammer is attached to the iron armature, A, which is supported by the flat spring, S. At C is a screw whose point touches the armature, while M represents an electromagnet. The ap-

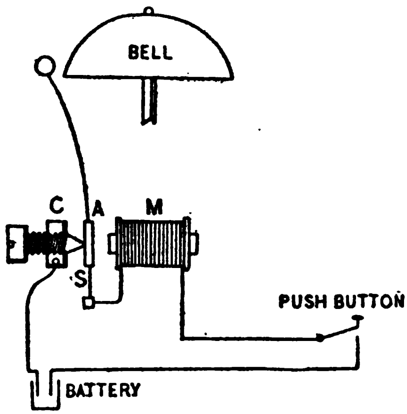

FIG. 6

paratus is so constructed that the circuit from the battery passes through the push-button, or other device, used in closing the circuit, thence through the electromagnet to the spring and armature, thence through the contact with the point of the screw, C, and thence back to the battery. When the circuit is closed at the push-button, the electromagnet attracts the armature, pulling it away from the screw, C, and causing the hammer to strike the bell. This interrupts the circuit at C, however, and deprives the electromagnet of its magnetism. The spring,

S, forces the armature back, drawing the hammer away from the bell and again closing the circuit at C. This again renders the electromagnet active, causing another stroke of the bell and another interruption of the circuit. The hammer thus vibrates, continually striking the bell as long as the push-button is held closed. If the hammer and bell are removed the armature will vibrate rapidly, making a loud buzzing sound, and the instrument becomes the familiar " buzzer."

The ordinary push-button consists simply of two pieces of spring brass mounted in a wooden shell and normally sprung apart out of touch with one another. By pressing a porcelain button, which projects through the casing, the brass pieces are brought into contact.

The annunciator is an instrument used when it is desired to know which one of a number of push-buttons, or other signaling keys, communicating with the same bell or other receiving mechanism, has been operated. One form consists of a number of small shutters, corresponding with the number of push-buttons in the system, each of which is held in place by a trigger, which may be released by an electromagnet. One of these electromagnets is included in the circuit from each push-button. When the latter is pressed the trigger is released and the corresponding shutter falls. The shutter and trigger are restored to their normal position mechanically by pressing a knob at the bottom of the annunciator. Another form of annunciator employs small swinging steel needles hanging near the cores of the electromagnets. When one of these becomes active it attracts its corresponding needle. As the latter is a feeble permanent magnet it does not fall back, but remains in the indicative position until mechanically re-

placed to its original position. The familar door-opening apparatus is a similar mechanism, a spring automatically returning the bolt to the locking position when the electrical circuit is opened.

A word concerning the care of domestic electrical apparatus. Dry batteries, when they show signs of failure, may often be rejuvenated by soaking them over night in a pail of water. They should be entirely immersed. A good dry cell should last about a year in ordinary domestic service. It cannot be renewed in part, and when exhausted, should be thrown away. The most frequent troubles with electric bells are due to dust, dirt and insects, such as spiders. Bells should be dust and bug-proof; it is unwise to buy any other kind. The contact between the set-screw, C, and the armature, A (see Fig. 6), should be surfaced with platinum. All other metals corrode and oxidize, causing the bell to stop working until the contacts are cleaned. Burglar alarms should be tested every day if they are expected to be in good order at night. Thermostat fire alarms should occasionally be tested by holding a lighted match under them. If they do not respond, something has gone wrong.

When sal ammoniac batteries are used, too much water should not be used, and a single carbon cylinder will often outlast several zinc pencils. These batteries often fail because of polarization. A good plan is to carefully clean new zinc pencils with some dilute acid and bring them in contact with a mercury bath. The mercury amalgamates with the zinc, forming a plating which greatly increases the effectiveness of the battery.

CHAPTER VII

THE RELATIONS BETWEEN MAGNETS AND ELECTRIC CURRENTS

In order to proceed to the understanding of the telephone it will be necessary, first, to study somewhat carefully the mutual actions of electric currents and magnets, and of currents upon one another.

A permanent magnet is a piece of steel which has been given the property of magnetism either by rubbing it on another magnet or by surrounding it by a coil of wire carrying an electric current. When hard steel is magnetized it retains a large portion of its magnetism indefinitely, and is then called a permanent magnet. Soft iron can also be magnetized very powerfully, either by a current-carrying coil or by being brought close to or in contact with another magnet or electromagnet, but it instantly loses its magnetism when the exciting cause is removed. Both kinds of magnets, permanent magnets and electromagnets, behave alike in all respects. Both attract iron or steel. Both exhibit points at which the magnetism seems concentrated, and which are called poles. Every magnet has two poles, and only two. If a magnet is suspended so that it can turn freely, it always hangs so that the line adjoining its two poles is approximately north and south. In any given magnet the same pole always turns to the north when it is free to move. The pole showing this tendency is called the north pole, the other being called the south pole. Neither kind of pole can exist without the other, every

magnet having both kinds, which, also, are of equal power.

If two magnets are brought together, it will be found that the poles of unlike names attract each other, while the poles of like names repel each other. A north pole of one will attract the south pole and repel the north pole of the other.

The precise nature of magnetism is not known. For convenience, and to enable us to think about it with

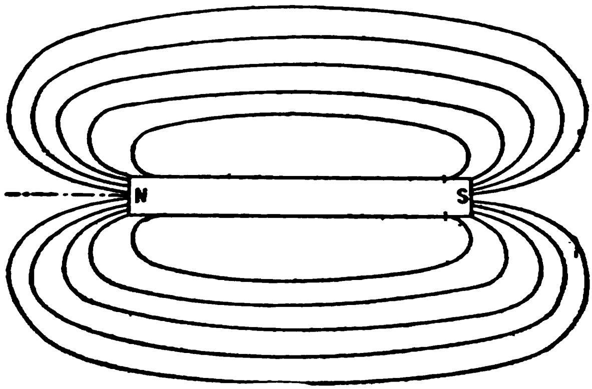

FIG. 7

ease, the conception originated by Faraday is generally employed. A magnet may be supposed to pour out some sort of effluvium, some subtle influence from its poles. This magnetic force may be supposed to come out of the north pole and return to the south pole of the magnet, flowing along lines such as are indicated in Figs. 7 and 8. These are called *lines of magnetic force.*

Now it is known from experiment that lines of force have the property of tending to shorten themselves—in other words, to become straight lines—while at the same time they also tend to repel each other sideways. Iron

and steel form an easy path for lines of force, while the atmosphere is much less permeable to them. Hence they will always pass through an iron or steel object in preference to passing through the air.

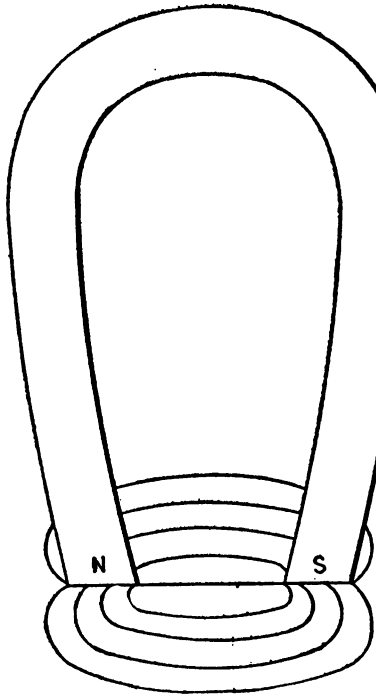

Fig. 8

We can now see how a magnet may render a piece of steel or iron magnetic and attract it.

Referring to Fig. 9, N S represents a bar magnet and *n s* a piece of iron. The lines of force coming out from N in part choose the easier path and pass through *n s* instead of through the air in returning to S. There is thus a bundle of lines passing between N and the nearest

point of the iron, and along these is a definite pull, since they tend always to shorten themselves. Where lines of force enter iron they create a south pole; where they come out of the metal, a north pole is formed. It will be seen by inspecting the diagram that not only is the piece of iron attracted to the magnet, but that it also becomes a magnet itself. This phenomenon is called magnetic induction.

Now, in order to make a magnet of a piece of iron, all that is necessary is to make lines of magnetic force pass

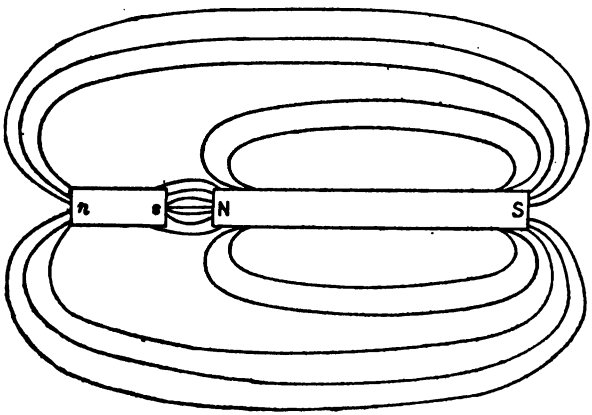

FIG. 9

through it. It is known that every current of electricity flowing along a wire, for example, is surrounded by loops of magnetic force lines. Why, we do not know; it is one of the fundamental facts of nature. In Fig. 10 is shown a cross-section of such a wire, the current being supposed to flow downward through the plane of the paper, while the magnetizing force circulates around it in the direction of the hands of a clock. Suppose we coil such a current-carrying wire into a helical coil, like

a corkscrew or an ordinary coil spring. Figs. 11 and 12 show that inside such a coil the magnetic force lines would all run in one direction. Hence a piece of iron inserted in it would become an electromagnet. In the case shown in the illustration, where the current is sup-

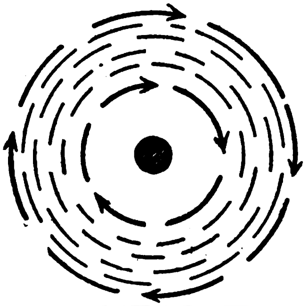

FIG. 10

posed to flow around the helix so that it goes down through the paper at the upper part of each turn, the north pole of the resulting electromagnet would be at the left. If the direction of current flow were reversed, the north pole would be at the right.

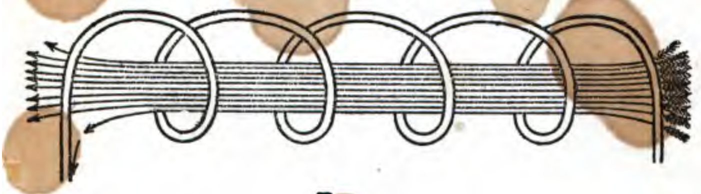

FIG. 11

Not only can current flow thus cause magnetism, but magnetism *in motion* can cause electrical pressure which will result in flow of current if a proper conducting circuit exists. If a wire is moved so as to cut across magnetic lines of force (or if the magnetic lines are moved so as to cut across the wire) a perfectly definite electrical

pressure will be set up, depending upon the velocity of the movement, the length of the wire and the strength of the magnetic field—that is, the number of lines of force contained in a given area of the region traversed. If the two ends of the wire are not connected no current flows.

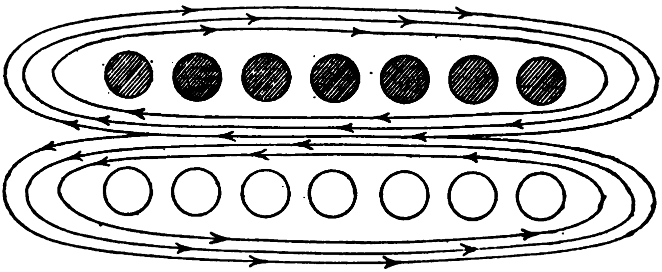

FIG. 12

If they are connected current will flow and the movement of the wire will be resisted in proportion to its amount.

It has already been stated that a wire carrying a current is surrounded by loops of lines of force. When the

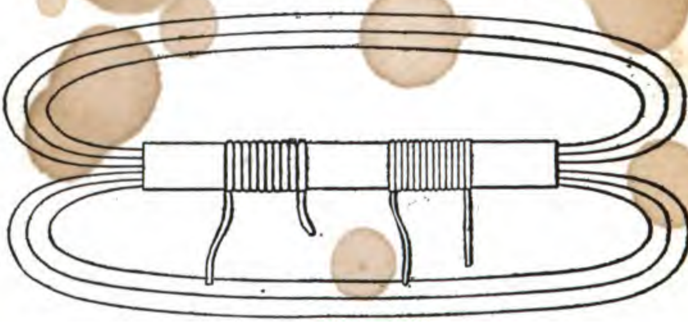

FIG. 13

circuit is closed and current started, these are not formed instantly, but expand outward from the wire with great swiftness until they fill the neighboring space. Similar-

ly, when the circuit is broken these loops contract and shrink into the wire until all have disappeared. In ordinary straight wires these actions take place with almost infinite rapidity.

If another wire is situated near and parallel with the first, it will be cut by the outrushing and inrushing loops of lines of force when current is made or broken in the first, giving rise to the phenomena of induction already mentioned in Chapter IV.

If two coils of insulated wire are placed on the same iron core, as in Fig. 13, and a current is sent through one of them, establishing lines of force in the iron core, and outside it, these will cut the second coil and establish a momentary current in it. If current is stopped flowing in the first coil another momentary current will flow in the second, this time in the opposite direction. If the current in the first coil is constantly reversed in direction, a similar constantly reversing or alternating current will flow in the second coil. Such an apparatus is called an induction coil or transformer. It is of great value in the arts, especially in telephony and power transmission, as will be explained in the following chapters.

CHAPTER VIII

INDUCTION AND REACTIVE COILS

A familiar form of the induction coil is the so-called "medical battery," or machine for giving electric shocks. A diagram of this machine is shown in Fig. 14.

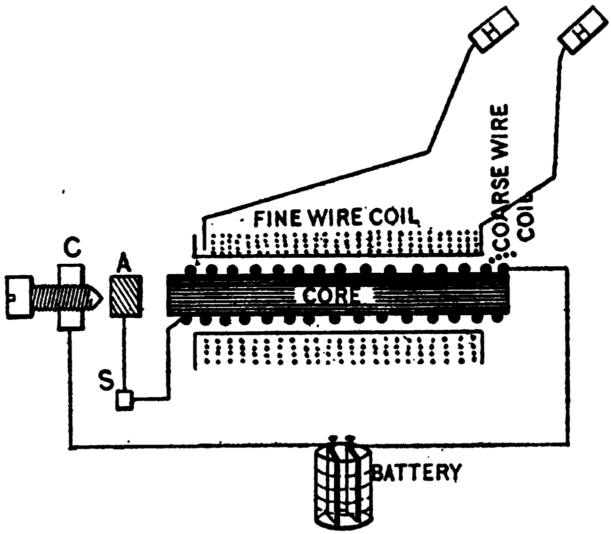

Fig. 14

Upon an iron core, generally consisting of a bundle of straight soft iron wires, is wound a coil consisting of a relatively small number of turns of a coarse gauge of insulated copper wire. An arrangement precisely the same as that employed in the vibrating electric bell (see Fig. 6) is used to interrupt the current flowing in this coil, causing the iron core to be very rapidly magnetized

and demagnetized. On top of the coil of coarse wire, but very carefully insulated from it, is wound another coil consisting of many thousands of turns of very fine insulated wire. This is constantly cut by the lines of force passing in and out of the core as it is alternately magnetized and demagnetized. On account of the great length of wire in this secondary coil of fine wire and the rapid cutting of lines due to the sudden magnetization and demagnetization of the core, high electrical pressures are generated in it, much higher than that of the battery. If the handles H-H are grasped electrical shocks will be felt, whereas the pressure due to the battery is insufficient to give a sensible shock. In large coils, such as are used in the production of X-rays (see Chapter XXIII) pressures of many thousand volts are generated sufficient to maintain a shower of powerful sparks, lightning flashes in miniature, between the terminals of the secondary coil.

The spark-coil, used in electric gas lighting apparatus, cigar-lighters and for igniting the explosive mixture in gas engines, takes advantage of the property of "self-induction" exhibited by coiled circuits. It consists simply of a bundle of straight iron wires surrounded by a coil of several hundred turns of insulated wire. If the circuit from one or two cells of battery is broken suddenly, a small bright spark is seen. If such a coil as is described above is included in the circuit the spark is much larger and more intense. The reason for this action is that at the instant of opening the circuit the magnetic lines of force withdrawing into the core of the coil cut every spire of wire in such a way as to produce an instantaneous and large increase of electromotive force, or electrical pressure, in the circuit.

The transformer is a variety of induction coil used in electric lighting and power transmission by alternating currents and will be fully described in the chapters devoted to electric lighting.

In telephony it is sometimes desirable to interpose in a circuit some device that will permit vibrating and alternating currents to pass through it, but which will interpose an infinite resistance to the passage of ordinary one-way or direct current. What are called repeating coils are used for this purpose. They consist of two similar coils of insulated copper wire wound on a core of fine iron wires. A steady current in one coil simply magnetizes this iron wire core, and after the magnetic lines of force due to it are established, in a brief instant of time, there is no flow of current in the second coil. If, however, the first coil is traversed by rapidly fluctuating or alternating currents (to which category the currents used in ringing telephone bells and transmitting telephone conversations belong) the fluctuating field of magnetic force set up will engender similar currents in the second coil. If the two coils are connected in two different circuits it is evident that, while the two circuits are entirely insulated from one another, alternating or pulsating or fluctuating electric currents flowing in one circuit will be repeated in the other.

An *alternating current* is one that is regularly and periodically reversed in direction. In engineering practice such currents are reversed from 50 to about 300 times a second.

Pulsating currents are those which flow in regular periodical pulses or waves in the same direction. The current in the circuit of a vibrating bell is of this character.

Fluctuating currents are those which are constantly changing in direction or intensity, or both. The best example of these is the current employed in telephony.

Direct or *continuous currents* are those that flow steadily and without change or interruption in the same direction, much as water flows through a pipe under a constant head and constant discharge.

CHAPTER IX

THE TELEPHONE

The telephone depends for its operation upon the accurate reproduction in the receiving instrument of the vibrations into which the sound of the voice at the transmitting end throws a part of the transmitting apparatus.

The simplest form of a telephone circuit, consisting of two ordinary receivers connected together, is shown in Fig. 15. Each receiver consists of only four essential parts; a steel bar highly magnetized, a coil of fine insu-

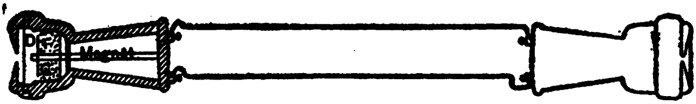

FIG. 15

lated wire wound upon one end of it, a thin circular sheet or diaphragm of varnished iron, and a conveniently shaped case for containing all these parts. The instruments serve as transmitters, also, the only essentials necessary for a telephone conversation being two of them, and the circuit of wires connecting them. As in telegraphy, the earth may be used for part of the circuit, requiring thus only one wire between the terminal stations. Grounded telephone lines do not work well, however, in these days when many powerful currents for trolley roads and the like are also "grounded" (using the earth as part of their circuits), as the telephone is almost incredibly sensitive to stray currents and disturbances which may be picked up.

When one speaks, his vocal cords set the air issuing from his lungs into vibration, and these vibrations are modified, strengthened here and suppressed there, by the action of the cavities of the mouth and nose, the position of the tongue and lips, etc. The vibrations producing the sounds of articulate speech are exceedingly complex and range from about 200 to about 4,000 to-and-fro swings of the air particles concerned in each second. If the left-hand instrument in Fig. 15, for example, is spoken into the air in the small chamber in front of the diaphragm (D) is thrown into vibration, and the diaphragm itself is caused to vibrate similarly, its central part advancing and receding perhaps a thousandth of an inch. Just behind and very close to this central part is one end, or pole, of the magnetized steel bar. The lines of force emanating from this go almost straight across the small air gap between it and the diaphragm (which is of iron), and stream out from parts of the surface and edges of the latter to find their way back to the other end of the magnet. In so doing they pass through the coil, C.

Now, the total magnetic flux, or number of lines of magnetic force, streaming from the magnet through the diaphragm and back, is dependent upon what may be called the magnetic resistance of the gap between the diaphragm and the magnet pole. The vibrations of the former alter this distance. If the diaphragm approaches the magnet the resistance of the air space to the magnetic flow is lessened and more magnetic lines spring out, causing a current to be generated in the coil, C. If the diaphragm recedes the air gap is increased, the number of magnetic lines decreases, and again a current is set up in the coil, C, but *in the opposite direction.* In this

way every movement of the diaphragm, accurately following the original sound vibrations, is faithfully reflected by a pulse of current in the circuit connected with the coil, C. The sound waves have been translated into electrical waves.

This fluctuating current, moving around the circuit, passes through the coil of the receiving instrument. This coil, acting upon the steel bar it surrounds, causes it to become an electromagnet. As the bar is already magnetized and is exerting a steady pull upon the middle of the diaphragm of its instrument, the fluctuating current circulating in its coil acts simply to strengthen or weaken the magnetism of the bar, according to which way the current is flowing in the coil, thus causing the pull on the iron diaphragm to vary in precise accordance with the fluctuations of the current. In other words, the pull on the diaphragm follows every vibration of the original sound wave, and the diaphragm itself, being elastic, is thrown into vibration, causing the air in front of it to vibrate just as does that in front of the diaphragm at the transmitting end. The ear placed close to the receiver perceives these minute air pulsations as a faithful reproduction of the original sound. In this way, by mechanism whose perfection is as remarkable as its simplicity, conversation may be carried on over great distances.

The magneto telephone, such as has just been described, is no longer used as a transmitter, as more satisfactory and powerful transmitting instruments using battery currents have been produced. One of these, which is typical of all, is shown in diagram in Fig. 16.

A great improvement in the art of telephony resulted from the invention of the battery transmitter. While

conversation could be carried on over lines of considerable length by the apparatus described above, consisting essentially of two ordinary receivers, one of which is used as a transmitter, still the power of the electrical impulse arising from such a transmitter is so small that on long lines, owing to resistance and leakage and other specific qualities of the line (which will be described more fully below), sufficient energy was not received to make conversation easy.

In Fig. 16 is illustrated in diagram the essential principles of the battery transmitter in general use. The

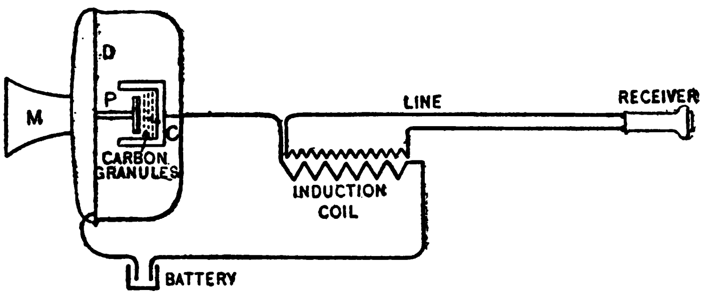

FIG. 16

principle of its operation depends upon a phenomenon discovered by Hughes and Edison, which is that the resistance of a mass of small particles of broken carbon is directly variable according to the amount of pressure exerted upon it. If such particles are compressed, their resistance becomes very much less than when they are simply allowed to rest together by their own weight.

The battery transmitter, in brief, consists of a cup, C, filled with granular particles of hard carbon about the fineness of ordinary building sand. Into this cup projects a plunger, P, attached to the middle of a diaphragm, D, in front of which is an air chamber con-

nected with the mouthpiece and so arranged that conversation in front of the mouthpiece sets the air in it, and hence the diaphragm, into vibration. This vibratory motion of the diaphragm causes the plunger, P, to work in and out in the cylindrical cup, alternately compressing and releasing the carbon particles. An electrical connection is made from a battery through the diaphragm, the plunger and the small particles of carbon to the back of the cup, and thus through the primary or coarse winding of the small induction coil. This coil usually consists of a core of fine iron wires, about three inches long, upon which is wrapped one or two layers of copper wire of a size comparable with coarse sewing thread. Over this is wound several thousand turns of fine, hair-like copper wire. The terminals or ends of this fine outside wire coil are connected with the line, at the distant end of which is a receiver of the type illustrated in Fig. 15. When this apparatus is talked into, the vibratory compression of the carbon particles causes their resistance to vary in direct proportion to the pressure upon them. The battery is furnishing a constant electrical pressure, while the resistance of the other parts of the circuit, the connecting wires, the battery itself and the coarse coil of the induction coil remain the same. In other words, the total resistance in the circuit is constantly being altered. Since the amount of current flowing depends solely upon this resistance and the pressure supplied by the battery, the current also increases and decreases, and while always flowing in the same direction fluctuates in a manner precisely similar to the vibrations of air in the mouthpiece of the transmitter and the chamber behind it.

These electrical fluctuations would themselves actuate

a telephone receiver and be intelligible as speech, but the available pressure which may be had from one or two cells of battery is not sufficient to cause currents of working volumes to flow through long lines. In order to obviate the necessity for having a battery of very large size—that is, of many cells—for each telephone, the induction coil is used to repeat into the circuit of the line a current of much higher pressure or voltage, but in all respects similar to that impressed upon the primary coil or winding. This current given out over the line is translated by the receiver into mechanical motions of its diaphragm, and these in turn impress themselves upon the contained air in the receiver chamber as audible waves of sound, reproducing the speech spoken into the mouthpiece of the transmitter. With apparatus of this character upon lines of good construction—those employing large copper wires in order to decrease the resistance, and carefully insulated—conversations are carried on daily with perfect ease over distances of 1,800 miles.

The apparatus described above constitutes all that is essential to telephone conversation. All of the other parts of telephone systems may be grouped under the heading of telephone accessories, since they are used simply in signaling that conversation is to begin or is at an end, or for connecting together telephone lines, as may be desired. They play no part in the transmission of conversation.

CHAPTER X

TELEPHONE ACCESSORIES

Taking the simplest case first, that of a line having one set of telephone instruments at each end, the accessories consist of call bells and switches, whereby, when the telephones are not in use, the connections with the battery are cut off so as to avoid the waste of battery materials which would ensue were the battery constantly

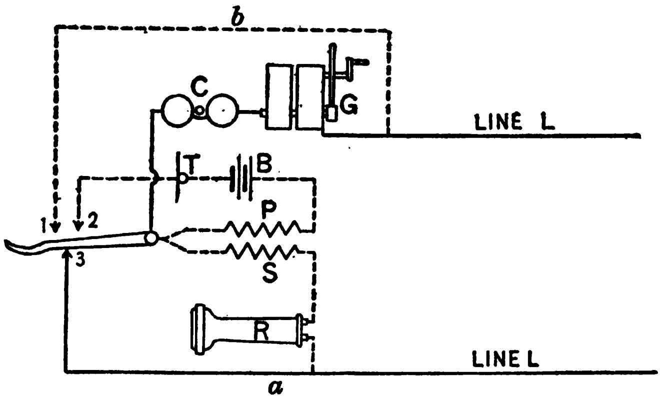

FIG. 17

to pour its current through the circuit. This arrangement is shown in diagram in Figs. 17 and 18. When the telephone is not in use, the receiver rests upon a hook, which is normally held up by a spring so that when the receiver is taken off and its weight removed from the hook the latter flies up to its upper position, closing the contacts 1 and 2, and opening the contact 3. This is the talking position. It will be noticed that the contacts 1

and 2, when closed, permit the battery to send its current through the transmitter and the primary winding of the induction coil. They also provide a path around the ringing mechanism, thereby taking the resistance of this apparatus out of the talking circuit. Through the construction of the ringing apparatus and bells their electrical resistance is necessarily high, and this method of bridging around them with a path of low resistance greatly adds to the efficiency of the telephone set.

Referring now to Fig. 17, which represents the ap-

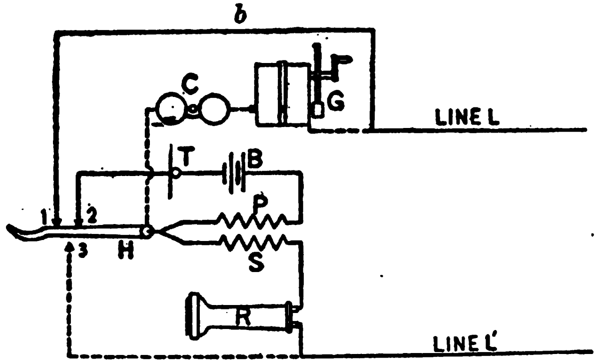

FIG. 18

paratus with the receiver hanging on its hook, it will be seen that the path of an incoming current is through the ringing mechanism and the bell, thence by way of the hook and contact 3 out to the other side of the line. If the proper variety of current for bell ringing is sent out from the distant station it will be received and the bell will be rung; but this current, it will be noticed, does not go through any part of the receiver, transmitter or induction coil. In response to the call thus received the receiver is taken from the hook, putting the apparatus in the condition exhibited in Fig. 18. In this the

path of currents over the line is by way of the short cut around the ringer, through the hook and the secondary or fine winding of the induction coil and the receiver, and thus back to the line. Current from the battery circulates through the transmitter, the hook and contact 2, and the primary or coarse winding of the induction coil. In this position both transmitter and receiver are ready for operation and conversation can be proceeded with. When conversation is finished and the receiver is again hung up, everything returns to the first position shown in Fig. 17, thus leaving the apparatus ready to receive another call or to send one out.

The bells employed on telephone lines are almost invariably of a type adapted to be worked by alternating currents. They consist generally of two electromagnets placed parallel with one another, and so connected together that the current sent through the two, produces similar poles at the same ends of the two.

This construction is shown in Fig. 19. M M are the two electromagnets. A is a bar of hard steel highly magnetized and pivoted at its center so that it may swing toward the poles of the electromagnets alternately. Attached to the middle of this swinging armature is the hammer, H, resting between the two bells, B B. When alternating currents pass through the electromagnets the poles presented to this armature alternately change, and with each wave of current in the one direction or the other attract one end and repel the other of the swinging armature. The armature is thus caused to oscillate rapidly on its pivot, the hammer striking first one bell and then the other. This variety of bell is known as a polarized bell, and very many apparatus used in telephony and telegraphy depend upon this method

of construction to give oscillating or vibrating movement from an alternating current.

The ringer or magneto generator for producing this current may be considered for the moment as a mechanical apparatus for producing alternating currents. Its description is deferred for the moment and will be taken up in Chapter XI.

Consider now the case of a line upon which several telephones are connected. There are two ways of accomplishing this connection, which are shown diagram-

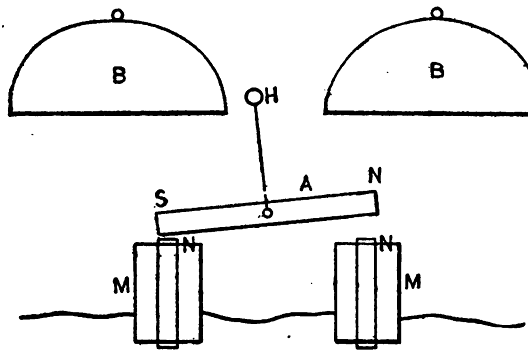

FIG. 19

matically in Fig. 20. The telephone instruments may either be connected one after the other, tandem, along the line, so that the current emanating from any one of them will traverse all the others one after the other in series. This method of connection is called "series connection." Another method is to connect each instrument across the two sides of the line so that the current emanating from any one will flow by the line, dividing itself between the others. This system of connection is known as "bridging connection," and is the method that is practiced in long lines almost universally. Of

course, as in telegraph lines, the earth may be used for one side of the circuit either in bridging or series connection. It is evident that when the telephones are in the position shown in Fig. 17, the ringing mechanism and bells of all will be connected to the line. Since the bells and ringers both contain great lengths of very fine wire having high resistance, the series method of construction necessitates that the talking current shall pass through this resistance, so that conversation from one end of such a line of telephones to the other will be considerably impeded. It is also necessary that the ringing mechanism should be of great strength, producing cur-

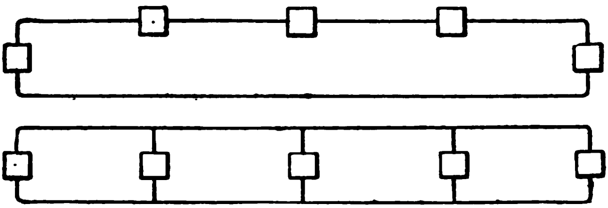

FIG. 20

rents of high pressure in order to traverse the telephones so connected.

In the bridging method of connection, however, the resistance of the bells, ringers, etc., being high, causes only a small part of the talking current to complete its circuit through their coils, thus leaving the line virtually clear for conversation at any distance. It may be remarked here that coils of fine wire possess the property of self-induction to a high degree, and that the rapidly fluctuating currents used in telephony find it practically impossible to penetrate a coil having this property. For this reason the bridging lines operate almost as well as if intermediary telephone sets were totally disconnected

from it. This method of connection, while apparently an invention of great simplicity, has practically made possible long-distance telephony.

Far the greater number of telephones are connected to exchanges. A telephone exchange or central office consists of a collection of apparatus whereby the numerous lines coming in from its subscribers' telephones may be connected together at the will of the subscribers, so that one may talk with another, and disconnected when conversations are finished, leaving these lines ready for other connections. The apparatus used is essentially very simple, but in practice is of enormous complexity, owing to the great number of telephone lines that center in many modern exchanges. In its detail the apparatus required for each incoming line consists of an annunciator (see page 29), a form of terminal connections such that the operator, noticing that a call has been received from a particular line, may connect with it a portable telephone apparatus so as to receive the orders of the subscriber. This being done by means of flexible connecting cords, the circuit of the calling subscriber is connected to that of the subscriber to whom he desires to speak, and by means of a switching arrangement included in the circuit of the flexible cord connection a calling signal is sent out over the second or called line, ringing that subscriber's bell and notifying him that he is wanted at the telephone. A second annunciator, included in the same cord circuit, is so arranged as to give a visible indication when the two subscribers have finished their conversation, so that the flexible connections, line terminals and other apparatus may be restored by the operator to their original condition.

All of the apparatus employed depends for its work-

ing upon the principles already set forth. In older telephone exchanges the annunciators were of the shutter type, described on page 29, while to-day they generally take the form of small incandescent lamps mounted behind opal glass bull's-eyes upon the switchboard (the name applied to the collection of all the central station switching apparatus). Subscribers' terminals end on this switchboard in what are known as "jacks." Essentially, a jack consists of a tubular opening containing electrical contacts at its bottom end and on its walls, so that a plug thrust into it makes contacts with its tip and sides, respectively, with these connections. This plug is attached to one end of a flexible conducting cord, containing two wires, in the middle of which is connected the "clearing-out," or "conversation ended," annunciator, and also a key for connecting the subscribers' lines with a source of alternating currents for bell ringing. The other end of the same cord is provided with a similar plug, which may be thrust into the jack of the called subscriber.

Where the number of lines entering a telephone exchange is small enough for all of the jacks to be gathered upon a switchboard of such dimensions that one operator may reach all parts of it from her seat, and where the services of only one operator are necessary (on account of the small volume of business) to handle all the incoming calls from subscribers, this arrangement is sufficient. Where, however, the number of entering lines is larger, requiring a larger switchboard, so that the incoming jacks occupy space larger than can be used by a single operator, and where also the volume of business is too great to be handled by one operator, many complexities are introduced. It is evident that

each operator must know whether a called line is busy. The most usual construction adopted in large exchanges is what is known as the multiple switchboard. In this switchboard, the incoming jacks are apportioned a certain number—sometimes not more than twenty—to each operator, while in front of each operator are collected other jacks of similar construction, but made as small as possible, one for each line connected with the exchange. For example, if the exchange has 2,000 subscribers, there will be 2,000 of these jacks—called "answering jacks"—in front of each operator; or, if ten operators are employed, 20,000 such jacks in all. Similar jacks at each position are connected together and to a subscriber's line, each line thus having its terminal duplicated in front of each operator. By appropriate connections with these jacks, signals are given an operator attempting to plug in to any one of them indicating if that line happens to be busy, or if one of its jacks at other operators' positions is already occupied by a plug. It will be noted that this method of switchboard construction becomes increasingly complicated as the number of lines increases. Up to the present, the largest switchboard on the multiple system that has been erected is that of the New York Telephone Company, at its Cortlandt Street exchange, where 9,000 lines enter and 9,000 jacks are duplicated in front of each of 232 operators' positions, making a total of 2,088,000 jacks.

The description of the details of a telephone exchange system is unnecessary for the purpose of this book. Enough has been said above to indicate that in the ordinary telephone installation in a city much the larger and more expensive part of the apparatus is at the central exchange.

The fact that the complexity of switchboards and exchange apparatus increases out of all proportion with the increasing number of lines connected explains the apparent paradox in telephone operation, that the larger the number of subscribers in a given exchange, the more it costs proportionately to handle the business done for each subscriber.

A recent improvement of great importance has been introduced in telephone exchange operation. Instead of providing each subscriber with a battery for operating his transmitter, these transmitters are operated by currents sent out from a large battery at the central office itself. At the same time appropriate connections with the hook switch at subscribers' instruments enable the sending in to the exchange of the signal that the attention of the operator is desired by simply removing the receiver from its hook. This action causes the annunciator lamp on the switchboard over the subscriber's incoming jack to light, and the operator, noticing this lamp, inserts the plug of a cord circuit into the answering jack for that line at her section, thus receiving the order for connection, which is made in the method described above. This system of telephone operation is known as the "common battery" or "central energy" system, and has lately been introduced in nearly all large central exchanges. It possesses many other advantages in celerity and quickness of operation, a description of which, however, would lead us too far into the technicalities of telephone exchange manipulation.

CHAPTER XI

THE MECHANICAL GENERATION OF ELECTRICITY

It has already been shown that a region permeated by streams of magnetism surrounds and connects the poles of a magnet. This region is called a field of magnetic

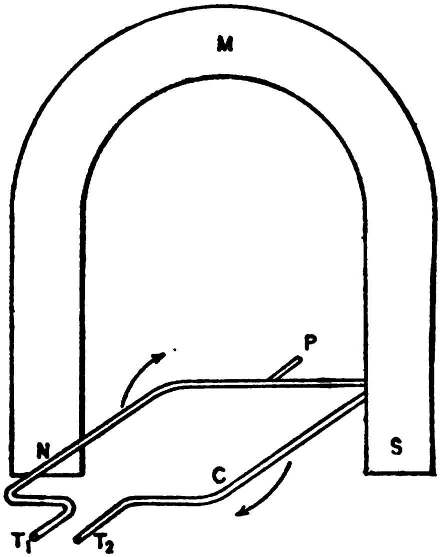

FIG. 21

force, or more briefly, a magnetic field, and the paths of the magnetic lines are called " lines of force." If a conducting substance is moved so as to cut *across* these lines in a magnetic field, an electrical pressure, or electromotive force, is set up in it, and if a conducting circuit is in proper connection with the extremities of the moving conductor a current will flow. Hence, to obtain

an electric current, all that is needed is some contrivance by which a conductor can be moved in a magnetic field, with appropriate arrangements for making contact with

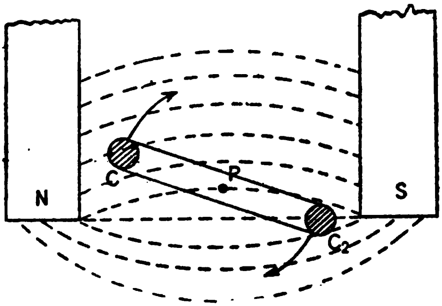

FIG. 22

it and withdrawing the current. Such a machine is called an electric generator. Its invention laid the foundation for all the applications of electricity to lighting and power purposes with which we are now familiar.

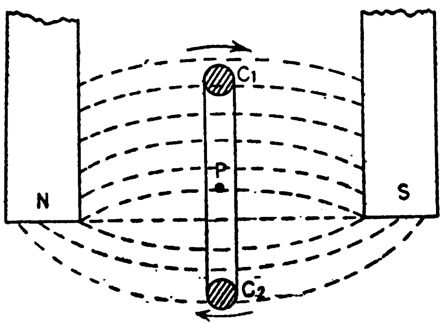

FIG. 23

In Fig. 21 is shown the skeleton, so to speak, of such a machine. M is a magnet having its poles at N and S. C is a loop of wire pivoted at P, so that it can be rotated in the direction shown by the arrows, while its two sides

alternately pass the two poles N and S. In Fig. 22 is shown the same arrangement, the wire loops being looked at endwise and shown in section.

If now this loop is turned in the direction of the arrows, the side marked C_1 will be the seat of an electromotive force or pressure tending to drive a current downward through the paper. The other side of the wire loop, C_2, is also cutting lines of force, but in this the pressure developed tends to make a current flow upward through the paper. If, now, the loop is connected in a closed circuit at its terminals T_1 and T_2 (Fig. 21), a current will flow around it.

As the loop turns it will presently arrive in the posi-

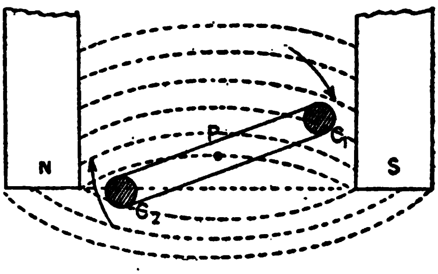

FIG. 24

tion shown in Fig. 23. Here the wires are, for the moment, not cutting the lines of force, but merely traveling parallel to them, and momentarily there will be no flow of current. When the rotation of the loop has advanced to the point shown in Fig. 24, the wires are again cutting lines of force and current is again flowing, but now it circulates around the loop in a different direction.

If, referring to Fig. 21, the terminals of the loop, T_1 and T_2, are connected to a conducting circuit, currents will flow in it, reversing their direction with every half

revolution of the loop. This machine is, then, a generator of alternating currents.

Such generators are used principally for ringing telephone bells and are familiar to everybody as the "magneto" ringing generator, to which power is applied by turning a small crank. These machines differ in some important respects from the skeleton just described. Their magnetic field is maintained by a powerful steel "horseshoe" magnet, or group of them. The rotating part, called the armature, consists of a coil of many turns of wire instead of a single loop. In order to strengthen the magnetic flux between the poles of the magnet, the interior of this coil is filled with a mass of soft iron, affording an easy path for the magnetic lines of force. The electromotive force or voltage obtained from a coil thus moving in a magnetic field depends upon the velocity of the motion, the length of the wire engaged in cutting the lines of force, and the strength of the magnetic field. In order to obtain the pressure necessary to drive the signaling current in telephony through many miles of wire and through the high resistance of the bell electromagnets, many turns of wire (a thousand or more) are employed, and the iron core of the coil is shaped to run very close to the magnet poles, which are hollowed out to receive it, thus narrowing the air space which affords a high resistance to the flux of magnetism. The same kind of hand-driven generators are used in firing blasting charges, but in these volume of current is desirable to heat the fuses. Consequently the resistance of the coil is kept down by constructing it of coarse wire. In both types, one end of the coil is connected to the shaft on which it turns, while the other end is connected to a metal ring concentric with the shaft and insulated from

it by a hard rubber bushing. On this last a spring rests, and by this means the electrical connection of the outside circuit to the moving coil is maintained.

Such a machine maintains an *alternating* pressure and alternating currents, or those periodically changing in direction, will flow through a circuit conected with it.

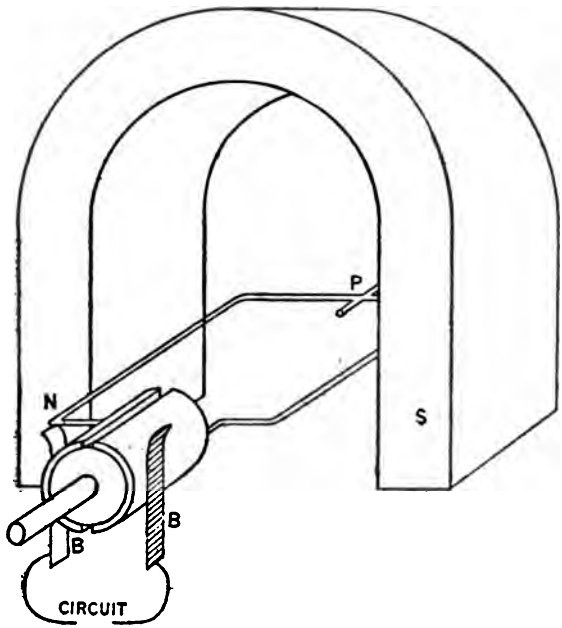

FIG. 25

For many purposes these currents are unsuitable, and it is necessary to rectify them, reversing in the machine itself all the impulses that tend to flow in one direction, so that all will traverse the circuit alike. This is accomplished by a device called a *commutator*. It is shown in its simplest form in Fig. 25. Here, for the sake of simplicity, the revolving coil is shown as a simple loop.

The two ends of this loop are connected to two metallic sectors turning with the shaft, in a way better shown in the engraving than it can be described. Upon these rest the metallic springs or " brushes," B B, from which currents are led off to the circuit. When the loop turns over and the current direction in it reverses (see Figs. 21, 22, 23 and 24), the two segments of the commutator have moved around so that, just as the current reverses in the loop, the interval between the segments passes under the brushes, thus connecting each with the opposite terminal of the coil. In this way the currents that alternate in the loop, flowing first in one direction and then in the other, are all made to flow in the same direction in the outside circuit. Such a machine is a direct-current generator.

CHAPTER XII

THE DYNAMO MACHINE

In machines designed to give the large volumes of electric current and the high pressures needed for electric lighting, a development of the simple mechanisms just described is used. For many mechanical reasons steel permanent magnets are not used in them, their magnetic fields being maintained by electromagnets which, in turn, receive their electrical energy from the moving coils of the armature. It may be explained here that the amount of electrical energy needed to maintain an electromagnet may be made as small or as large as convenience dictates. In the usual generator, not more than three or four per cent of the total electrical flow from the moving coils is utilized in keeping the field magnets in activity.

A generator having electromagnets to maintain its magnetic field is called a dynamo-electric machine, generally abbreviated to "dynamo." If these electromagnets are fed by currents generated in the machine itself it is said to be "self-excited"; if they are fed by currents generated elsewhere than in the machine it is said to be separately excited.

The principle of operation of such machines is the same as that of the telephone magneto bell-ringing machine described in the last chapter: conducting wires or rods are moved transversely in a magnetic field and the electrical pressures thus engendered are properly rectified in direction by a commutator, currents being

taken from the latter by appropriate brushes or sliding contacts. In order to condense such machines, the same armature, or iron core carrying the working coils or conductors in which pressures are set up, is often made to work in more than one magnetic field. We will consider a modern type of generator of this class, having four electromagnet poles. Machines having more than a single field of force, or what amounts to the same thing, more than two magnetic poles presented to the revolving armature, are termed multipolar dynamos.

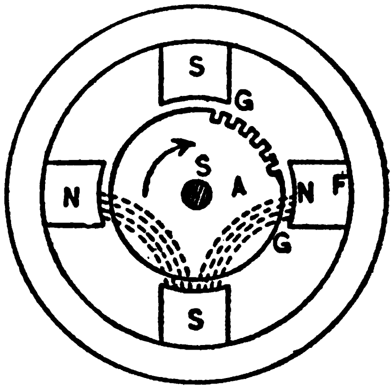

FIG. 26

Figure 26 shows the iron parts of such a dynamo in diagram. F is the field magnet, consisting of a cast-iron ring with internal projections N-S-N-S, called pole pieces. These are shaped to the curve of the cylindrical armature core, A, so as to make the air-gaps, G G, as small as consistent with the mechanical safety of operating the machine. This field ring and its pole pieces form the stationary part of the apparatus. The armature core, A, is supported by the shaft, S, in proper bearings (not shown in the diagram) and may be rotated by a steam

engine or other source of power. This core consists of a great number of disks of thin sheet iron, each slotted around its circumference, and after having been varnished, assembled by great pressure on the shaft so as to constitute practically a solid mass. This is in the shape of a cylinder with a slotted face, the width of the slots and the iron teeth between them being about equal. The object of laminating the core in this way, instead of making it of solid metal, is that electrical pressures are set up in the core itself, and these, owing to the almost insignificant resistance of a solid core, would set up enormous currents, heating the core and absorbing much energy.

Upon this iron frame the insulated copper wire circuit intended to magnetize the field and to generate currents when passing through the magnetic flux from the poles is placed. It is generally called the "winding," though in large machines very often copper bars or straps constitute it.

The field winding consists of coils of insulated wire so placed upon the four polar projections as to cause their faces presented to the armature to be alternately north and south poles. The magnetizing effect of these coils depends upon the number of turns or spirals of wire in them and the current (measured in amperes) flowing in them. These coils are so connected together that currents flow from the commutator of the machine through all of them in series and also through a device called a rheostat. This consists of a collection of strips or wires of material of relatively high resistance, and a switching appliance whereby more or less of them may be included in the circuit. With this rheostat the total resistance of the circuit in which the field coils are included may be

varied. If it is made greater, less current will flow and the magnetizing effect of the coils will be lowered. This will weaken the field of force in which the armature conductors turn, thus causing the electrical pressure generated in them to become less. In this way, in the kind of dynamo under consideration, the pressure generated by the machine may be varied or regulated.

The path of the lines of force flowing is clearly indicated in the figure. If we imagine a wire or bar laid in one of the slots and the armature turned it would cut

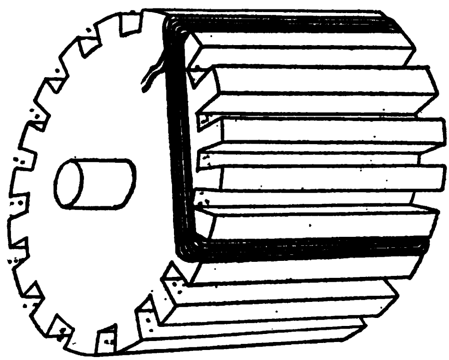

FIG. 27

lines of force as it passed each pole, the resulting pressures being first in one direction and then in another. If, now, a square cornered coil is constructed so that it may be placed in two slots one-quarter the distance around the armature core apart, as shown in Fig. 27, it is evident that in one complete revolution of the core each bundle of parallel wires forming one side of it, will pass through the flux from the four field poles, and that the coil as a whole (if its ends are connected together) will be traversed by four waves or pulses of current, two in one direction and two in the other.

Suppose, now, another coil is laid in the next pair of slots, to the right, for example, and then another in the next pair, and so on, until every slot has parts of two coils in it, the right-hand side of one and the left-hand side of the other. There will thus be as many coils as slots on the armature, and, as each coil has two ends, twice as many ends. Each coil is precisely like all the others, and as they are wound up ready to put in place, the ends of the wire in each are distinguished as the "starting" and "finishing," or "inside" and "outside" ends. As the coils lie in place in the armature

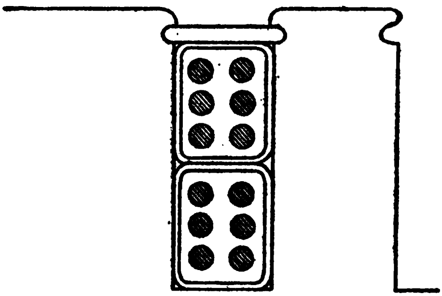

Fig. 28

slots, the "inside" end of each is connected to the "outside" end of its next neighbor. This leaves a number of pairs of connected ends equal to the number of slots. The coils are held in the slots by banding wires running around the circumference of the armature or, better, by wooden strips keyed into small notches in the walls of the slots, as shown in Fig. 28.

The commutator for a machine of this kind consists of bars of hard copper assembled in a steel shell and carefully insulated from the shell and from each other by strips of mica, a substance of high insulating qualities.

The individual copper bars are wedge shaped and lie radially, the whole commutator forming, when assembled, a cylindrical structure with its circumference equally spaced by the mica strips. The number of bars is equal to the number of slots, of coils, or of connected ends. Fig. 29 shows a simple type of commutator in section and end elevation.

Each bar has at one end a slotted ear into which one connected pair of coil ends is firmly soldered. When

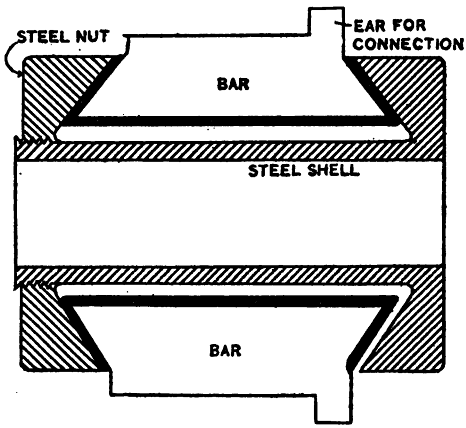

FIG. 29

these connections are complete, the armature is ready for use.

A careful consideration of the relations of the various coils and poles at any time will show that the pressures generated are such that at two points, diametrically opposite one another on the commutator there is a maximum effort to cause current to flow *out*, while at two other opposite points, half way between the former, the four being thus 90 degrees apart, there is a maximum effort to cause current to flow in. As the armature re-

volves, these points do not revolve with it, but remain stationary with reference to the field poles. It is at these points that the four brushes bear upon the commutator. Generally these consist of carbon blocks lightly held against the commutator by springs. Opposite brushes are connected together and from the two pairs current is led off by appropriate terminals to the connected circuit.

If the field frame has two poles there are only two points of maximum and minimum electrical pressure around the commutator, and only two brushes are required. A six-pole frame requires six brushes, and so on. By making permanent connections across from each commutator bar to its opposite only two brushes, applied 90 degrees apart, are requisite for a four-pole machine.

CHAPTER XIII

VARIOUS TYPES OF DYNAMO MACHINES

According to the service for which they are intended dynamos are built in a variety of classes. They may be made to furnish a constant pressure of any desired number of volts (up to a maximum imposed by the ability of commutator insulation to withstand high voltage) without reference to the volume of current flowing from them. They may also be made to furnish a constant rate of current flow through circuits of various degrees of resistance, such machines being used for arc lighting. Still another variety of dynamo is made to produce a rising pressure as larger currents are withdrawn, so as to compensate for the fall of pressure due to the resistance of long circuits and deliver at their extremities a constant pressure. The mechanical differences of design are also very numerous, being governed by considerations of permissible speeds, the nature of the applied power, etc.

A dynamo, such as that described in the last chapter, is called a "shunt" dynamo, the field magnetizing circuit being shunted or bridged around the armature circuit. In such a machine, with the speed of rotation constant, the pressure developed will fall off with an increase of volume of current withdrawn. In traversing the armature, the current encounters resistance, and suffers a certain fall of pressure due to energy expended in overcoming this resistance. The fall of pressure, in volts, is measured by the product of the resistance in ohms, multiplied by the current in amperes. Thus, from an arma-

ture having a resistance of one-half ohm, which, with the speed and the magnetism of the field constant, will produce a pressure of 100 volts, suppose a current of 10 amperes flows. The 10 x ½ or 5 volts are lost in overcoming its resistance and only 95 volts appear at the terminals. If 50 amperes are withdrawn, then 25 volts are lost and only 75 volts appear. In practice, where the current in the field winding, and hence the magnetic force, depends upon the terminal voltage at the armature, the variation is even greater, for the fall in voltage caused by the armature resistance also causes the field strength to fall off, producing a still further diminution in the pressure obtained. To obviate this difficulty and produce a machine that will give a constant voltage, regardless of the current flowing (so long as its speed is steady), the machine is provided with what is known as a "compound winding."

This consists simply in adding another coil on each field pole, through which the current flowing from the brushes of the dynamo to the circuit with which it is connected is caused to flow in the same direction as that in the winding already described. These coils constitute respectively the *series* and *shunt* windings. When current is withdrawn the weakening effect on the shunt field winding described above takes place, but the current taken off, flowing also around the poles, compensates for this and also for the armature resistance losses.

If, now, the dynamo has to deliver a fixed voltage at a distant point over a line of known resistance, the drop in voltage on this line may also be compensated by adding turns or spires to the series winding. In electric railway practice dynamos are often thus "over-compounded" so as to give, for example, 500 volts at the

end of a line of a given gauge of wire of a certain length and with a certain maximum of current flow.

The loss in electrical energy in traversing resistance is manifested as heat, as was explained in Chapter III. The limit of output of current in a dynamo is marked generally by its armature resistance and its capacity for ridding itself of the heat produced in it by this resistance. Practically all armatures are built so that air can circulate through them to assist in keeping them cool. If excessive currents are withdrawn, the armature conductors become so hot as to char or set fire to their insulation, or even to melt, thus causing a "burn-out."

Constant current dynamos for arc lighting and other purposes, where the volume of current required never changes, are not self-regulating like the machines described above. Usually some auxiliary apparatus is required. In general, this takes the form of a mechanism to shift the position of the brushes on the commutator. As stated in the preceding chapter, there are points on the commutator, corresponding to the number of poles, of maximum and minimum pressure. Upon these the brushes of constant voltage machines bear. Between these points are others of no pressure. By shifting the brushes backward or forward between these, any pressure up to the maximum the armature can produce may be found. The shifting is accomplished by electromagnets through which the working current passes. If the current increases in volume, the electromagnet pulls the brushes around to a point of lower pressure, thus reducing it; if the current falls off in volume, the reverse action takes place, and the brushes are shifted to a position of higher pressure. In dynamos of this type there is no shunt field, the whole of the outgoing current cir-

culating around the field magnets. As this current is of constant volume, the magnetic field also remains constant. Dynamos of this type have a different arrangement of armature winding from that described in the last chapter, the various coils of their winding being left unconnected with one another. Constant current dynamos, maintaining about 10 amperes flow of current, at pressures ranging from 50 to 4,000 volts, are in common use for arc lighting.

In all dynamos it requires power to drive the armature conductors through the magnetic field when current is flowing in them, the power (at the same speed and field strength) being precisely proportional to the product of the current flow and the voltage. In other words, to drive these machines requires an amount of power proportional to the watts of energy they impart to the connected circuit, and an additional amount equal to whatever is consumed in heating the armature and field windings, in magnetizing and reversing the magnetism of the armature core, and in mechanical friction in the machine itself. These losses are reduced in well designed machines to a small proportion of the total, the amount of electrical power (in watts) produced being a large percentage of the mechanical power applied. In large machines this percentage, called the *efficiency* of the machine, is often over 95 per cent. For this reason, the dynamo, although an apparatus of recent development, is probably the most efficient appliance known to the mechanical arts.

CHAPTER XIV

ALTERNATORS—POLYPHASE CURRENTS

The dynamos described in the last two chapters are adapted to generate direct currents, or those flowing always in the same direction. Another very important type of machine generates alternating currents only, currents in which the direction of flow is periodically reversed. Such machines are called alternators.

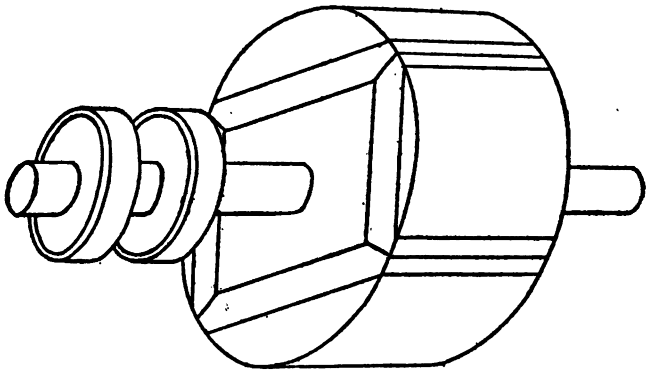

FIG. 30

Their principle of construction is similar to that described for direct current generators, but instead of providing them with commutators to rectify the constantly reversing pressures generated in their armature coils, these alternating pressures are used directly to cause alternating current flow in the connected circuit. If, upon the armature core illustrated in Fig. 27, four coils are laid, in the manner shown in Fig. 30, the intermediate slots of the armature core now being left vacant, or, as shown in the illustration, only four slots being provided,

and the proper connections made, the dynamo will become an alternator. These connections are as follows: Two rings, insulated from the shaft and each other, take the place of the commutator. To one of these, one end, the inside, we will say, of one coil is connected; the other or outside end of this coil is connected to the outside end of the second coil; the inside of coil No. 2 is connected to the inside of coil 3; the outside of this to the outside of coil 4, and the inside of this last coil to the other ring. When such an armature turns in a field, such as is shown in Fig. 26, the bundles of parallel conductors lying in the slots all cut the fluxes of magnetic lines from the pole faces at once, and the total electrical pressure set up in all of them is communicated to the two rings connected with the first and last coil terminals. Upon the collector rings brushes bear, from which the alternating currents are led off to the circuit.

Evidently such a machine cannot excite its own field magnetizing coils, since the alternating currents evolved by it would not produce the necessary steady magnetic flux. Consequently a small direct-current dynamo is provided for exciting the fields, one such machine often serving for a group of alternators.

For mechanical reasons it is very often more convenient to make the field magnet the revolving and the armature the stationary element of an alternator. This construction is easily imagined. The outer ring is built up of laminated iron plates (soft steel is often used) with slots cut in its inner face to receive the armature conductors. The field magnet is built with outwardly projecting radial poles, the current for its magnetization being led in through brushes and collector rings as de-

scribed above. In this case the armature terminals are simply stationary binding screws to receive the wires leading to the line. Since the armature coils are stationary and not subject to mechanical stresses from the motion of rotation, as is the case when the armature is the revolving part, they may be most elaborately insulated

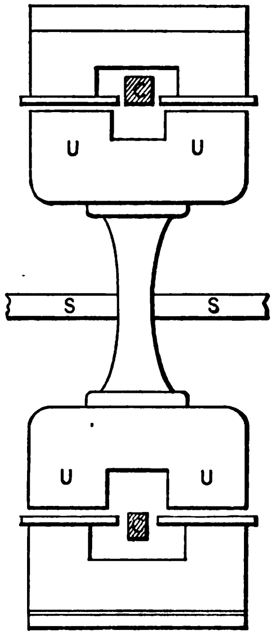

FIG. 31

with materials of good non-conducting quality, which would be unable to stand the strain of rapid motion. For this reason, such stationary armature machines are extensively used when it is desired to generate very high voltages. Pressures up to 15,000 volts are now generated in machines of this character in commercial installations.

Still another type of alternator is that in which there

are no moving conductors at all, the rotating part acting simply as a bridge to carry the magnetic flux from stationary field coils rapidly past the conductors of a stationary armature. These machines are called "inductor alternators," the moving part being the inductor. Fig. 31 represents in diagram such a machine. The field coil, C C, is attached to the frame of the machine and causes a strong flux of magnetic lines of force to flow in the U-shaped iron pieces, U U, which are bolted to a "spider" or hub turned by the shaft, S. Each of these pieces is an electromagnet having two poles.

The outer ring is the armature, and is built up of laminated iron plates, with slots cut in its inner face to receive the armature conductors. As is seen, there are two sets of windings, the machine being practically a double generator. Between the two armature windings lies the large circular field coil, attached to the stationary armature core. The moving part of the machine, lying within, consists of a cast steel spider, upon which are bolted projecting poles built up of sheet iron. The path of the flux is then from one armature surface across the gap to the projecting poles of the inductor, along the cast-steel spider, and out through the poles at the other end; thence across the second gap and into the second armature core, and back to the starting point.

As the inductor is revolved, the points of the armature surface from which the flux passes to the rotor will be shifted continuously, and the effect produced will be similar to that caused by the revolving field of the machine last described.

These machines are occasionally built with but one armature winding, the second winding being dispensed with.

CHAPTER XV

THE ELECTRIC MOTOR

The dynamo is a machine that converts mechanical power into electric current. Conversely, the electric motor is a machine that converts electric currents into mechanical power. Their construction is identical, and any (direct-current) dynamo can be used as a motor and any motor as a dynamo. The same machine answers both purposes.

Like dynamos, motors are shunt, series or compound wound. They are made to operate under constant pressure of voltage or under constant flow of current, the former type being by far the most numerous. They are made in two-pole and many-pole types, to run fast or slow, and in sizes from toys that can barely turn themselves up to great machines of several thousand horsepower.

The principle of their operation is as simple as that of the dynamo. If a conductor in a magnetic field is moved to cut the lines of force, a current tends to flow in it, and if a conducting path is offered the current will flow. If, now, current is made to flow in a conductor in a magnetic field, then the conductor will tend to *move*, and if free to do so will move so as to cut lines of force. And the direction of the motion will be such as to generate in the moving conductor an electrical pressure *opposed* to that causing current to flow in it. In other words, the free conductor tries, apparently, to stop the flow of

current through itself by moving so as to generate a current in the opposite direction.

Referring to Chapters XIII and XIV, and to the diagrams of a dynamo, Figs. 26 and 27, it will be noticed that if an electrical pressure is applied at the terminals of the dynamo (or motor; they are the same) two currents will be caused to flow: One will circulate through the field winding, magnetizing the field. Another will go through the armature conductors, which will tend to move, all in the same direction, and thus cause the armature to rotate.

If the armature were held so it could not rotate, the current in it would depend simply upon its resistance and the applied pressure. As the resistance of an armature is generally very low, the volume of current flow would be very great, were the armature not free to rotate. It does rotate until the back pressure or " counter-electromotive force " generated in it very nearly balances that applied to the machine.

Let us take the case of a shunt wound motor with an armature having a resistance of one ohm, and which, operated as a dynamo at 1,000 revolutions per minute gives a pressure of 100 volts. Suppose a pressure of 100 volts is applied to the machine by connecting it with the electric light circuit, for example. Then the field magnetism will obviously be of the same strength as before, and the armature will rotate so that it generates very nearly 100 volts back pressure. The *difference* between this back pressure and the applied pressure will cause a current to flow in the armature, and this current, multiplied by the total pressure under which it flows—the applied pressure upon the terminals of the machine (100 volts)—will measure the electrical power exerted. Sup-

pose 250 watts are consumed in overcoming friction, etc., then 2.5 amperes must flow, requiring a difference of pressure of 2.5 volts. The armature must, then, run fast enough to generate 97.5 volts. As the voltage it generates is proportional to its speed, and it generates 100 volts at 1,000 revolutions per minute, it evidently will run at 975 revolutions per minute when no external load is applied to it.

Suppose, now, the motor is connected to a machine of some sort requiring one horse-power, 746 watts, to drive it. Then the total load is

$$746 + 250 = 996 \text{ watts.}$$

To produce this energy, a current of 9.96 amperes must flow, requiring a difference in pressure of 9.96 volts (since the armature resistance is one ohm), and the armature therefore will turn at such a speed as to generate $100 - 9.96 = 90.4$ volts. This means that it will turn at 904 revolutions per minute.

Thus, the motor slows down under load. If its armature resistance is made smaller it will not slow down so much. Indeed, in practice, shunt motors having armatures of low resistance are very nearly self-regulating as regards speed. To make them precisely so, a series coil is added, as in the dynamo, to the field winding, but in this case it acts *in opposition* to the shunt coil, since the effect of weakening a motor's field is to make the motor run faster. The series coil can thus counterbalance the tendency to slow down on load.

The series motor is of great importance. In this machine the field windings and the armature are connected so that the same current permeates both. If a series motor has a constant electromotive force applied to it, it

will start from rest with a large current, due to the small resistance of the machine, and very powerfully magnetized fields. As the armature gathers speed and begins to generate counter-electromotive force it presently reaches a speed determined by the load upon the machine and the pressure applied. If the load is released the motor will attain a very high speed, or "run away." But if it is started with the load on it, it will exert its maximum starting effort or "torque" at the moment of starting. This is very important in some applications, notably so in hoisting and in railway work, where getting the load started promptly is important.

The "power" or rating of a motor depends solely upon the maximum current its conductors will carry under the given impressed voltage for which it is built. Any motor, shunt, series or compound wound, will "keep on trying," so to speak, to move any load connected with it until it actually "stalls" or the currents flowing in it heat the conductors to the danger point and something gives way. For this reason, in practice, motors are connected to their feeding circuits through fuses or some other form of circuit breakers, which act when too much current passes. The fuse is simply a short length of conducting wire or strip of some easily melted metal or alloy, of such dimensions that a current approaching the danger limit of the motor will melt it and thus open the circuit. A circuit-breaker is a switch, containing a spring tending to throw it open and held closed by a trigger connected to the armature of an electromagnet through which the current in the motor circuit flows. The pressure required to throw the trigger is adjustable by another spring, and is set so that an excessive current causes the electromagnet to overpower

the spring, release the trigger, and thus cause the switch to fly open.

Motors are regulated in speed in various ways. Shunt motors are controlled by varying the resistance of the field circuit with a rheostat, thus causing them to run faster if the field is weakened by the insertion of resistance. They are also regulated by the variation of the impressed voltage. In numerous installations for driving machines in factories a number of circuits of different constant voltages are led to the various motors. The fields are connected to a given voltage, while that applied to the armature is varied by shifting its connections from one circuit to another. This so-called "multi-voltage" system is in very satisfactory use in many large machine works, etc.

Series motors are usually regulated by resistances connected in series with them (which is the same thing as by changing the impressed voltage) or by the use of subdivided field windings, of which more or less coils can be switched into circuit according as higher or lower speeds are desired. An interesting example of the regulation of a *pair* of series motors is discussed in the next chapter.

A few motors are used on constant current circuits, or those in which the same volume of current flows without regard to the resistance encountered. These motors are generally regulated by shifting their brushes. They are essentially similar to constant current dynamos, described on page 72.

Electric motors, on account of their convenience and reliability and their freedom from noise, dirt and heat, are used for innumerable purposes. They are adapted for practically all forms of work, and for many to which

no other motive power can be applied. Owing to their small size and ease of regulation they are now finding increasing use in the driving of individual machines and tools in factories and shops, thus doing away with belting and shafting. At present their most important application, considering the capital invested in it, is the electric railway, which forms the subject of the next chapter.

CHAPTER XVI

THE ELECTRIC RAILWAY

The electric railway consists essentially of only three elements—a generator of electricity, a conducting system extending along the route traversed and cars upon which are electric motors.

The description of an ordinary trolley road will be given here with some fullness as the best way to indicate the methods used in the operation of an electric railway of the ordinary type.

The power house or place where currents are generated contains a prime mover of some sort, either a steam engine or water wheel, this being of such a design that it runs at one steady speed whether lightly or heavily loaded. This prime mover drives one or more dynamos, or there may be several engines or water wheels, and several dynamos all arranged to work together, pumping current out upon the conducting lines parallel with the track.

It is customary nowadays for the engines or water wheels to be direct-coupled with the dynamos, that is, the armature or rotating part of the dynamo is built upon the engine or water wheel shaft. The two machines taken together are spoken of as a generating unit.

The dynamos used in electric railway work are almost invariably over-compound wound (see page 71), so that when no energy is being withdrawn from them they give a voltage of about 550 volts; when their full current is

being withdrawn this rises to about 600 volts. The object of this over-compounding is to compensate for the voltage drop in the conducting lines when large currents are taken off, and by having the pressure at the dynamo rise that at the car can be maintained quite steady.

From the dynamos copper cables are led to the switch board, which consists of marble or slate slabs supporting all the switching and connecting mechanisms together with volt meters and ampere meters; in other words, electrical pressure gauges and current flow indicators. The object of the switchboard is simply to gather all the controlling and indicating apparatus of the power house conveniently together in one place. From this switch board conducting cables are led to the two sides of the working circuit, which feeds the cars with current.

The working line consists of two parts, the track and a bare copper wire suspended above it and called the trolley wire. The cars are connected in multiple (that is, bridged, see page 52) between this wire and the track by means of the trolley wheel, which runs on the underside of the wire.

In order to carry the current necessary for many cars, the trolley wire would have to be inconveniently large. To avoid this difficulty large cables, parallel with the track, are placed on the poles supporting the trolley wire, or sometimes laid under ground, these being connected with the trolley wire at intervals of from 300 to 500 feet. The cables, which are called feeders, are connected to the station switch board. In general, each feeder coming out from the station feeds a definite section of trolley wire. These sections are insulated from one another so that an accident or breakdown on one will not interfere with the operation of the others. Each

feeder is provided with a circuit breaker, which is generally mounted on the switch board to protect its section of the line against excessive flow of current in case of accident.

The track, while built of steel rails, is not a very good electrical conductor. Rails are usually made in 30-foot lengths, and the joints between these lengths offer a considerable resistance to the passage of current, especially after they have become rusted in service. Consequently the rails are bonded together at each joint with copper bonds, of which many varieties are in use. A typical one is constructed of two copper rivets connected by numerous strips of sheet copper. A hole is bored through the thin part or web of each rail a few inches from the end and the copper rivets are forced into these immediately (while they are still clean and bright from the drill), either hydraulic pressure or blows from a hammer being used to expand the soft copper rivet until it fits the hole with perfect tightness. The copper strips connecting the rivets permit slight play or vibration of the rail ends to take place without breaking the connection.

While tracks thus connected have very low electrical resistance, in some places where the number of cars is great and the current flow large it has been found necessary to lay heavy copper cables parallel with the tracks and connected with them at intervals to increase their conductivity. These cables are brought back to the switch board at the power house, or in case they are not used, the nearest part of the track is solidly connected by a large cable to the switch board. One terminal of the dynamos is connected to the outgoing feeders; the other is connected to this track wire or "ground cir-

cuit." In this way the dynamo maintains a constant difference of electrical pressure of 550 volts between the trolley wire and the track. It makes no difference in the operation of the cars whether the current goes out via the trolley wire and returns by the track, or vice versa.

The electrical circuit of the car consists of the trolley, from which a wire goes to the controlling apparatus on the platforms, thence to the two motors and to the track, by way of the wheels. The trolley consists of a bronze wheel supported at one end of a hollow steel pole, which is pressed upward by springs on the roof of the car. The trolley has motion in two directions, both sidewise and vertically so that it may easily follow the trolley wire even if it is hung somewhat out of its proper place.

The two motors are series wound (see page 80). The function of the controller is to group the field windings and armatures of these motors and a resistance carried under the car in a number of appropriate combinations to give various speeds of running. The motors are of a four-pole type and are constructed so that they are entirely inclosed, thus keeping out dirt and moisture. Upon each motor shaft is a pinion engaging with a large gear wheel on one axle of the car. In general, the motor is allowed to run about five times as fast as the car axle. Two such motors constitute the motive equipment of a car. They are hung upon springs and also hinged to the axles they drive so that they may ride easily, so to speak, and at the same time maintain the gearing always in proper mesh.

From these motors cables connected with their brushes and the ends of their field windings are led to each controller. Only one of these is in service at a time. Under each car is a resistance composed of strap

iron insulated with mica, the terminals of this also being brought to the two controllers.

The controller consists of a vertical cylinder which can be turned by a handle projecting through the top of its case. Upon this cylinder are contact strips adapted to run under connecting fingers of brass when the controller handle is turned. Upon turning the controller handle to the first position, a circuit is established by means of these connections from the trolley through the resistance and thence through the two motors, one after the other, thence to the wheels and track. In traversing the resistance, a certain proportion of the electrical pressure of 550 volts is used up (in heating the resistance), while the remainder goes to the two motors. These being connected tandem or in series divide this remnant of the voltage between them and each starts gently and slowly.

The next notch on the controller cuts out the resistance and leaves the two motors connected still in series to the full 550 volts of line pressure. Under these conditions they move somewhat faster, each now receiving 275 volts.

The next step again inserts the resistance, but this time the two motors, instead of being connected one after the other in the circuit, are connected side by side, or parallel to each other, and now each receives that remnant of the line voltage not consumed in the resistance. This may be as high as 400 volts, causing the motors to turn still faster.

The last position of the controller again cuts out the resistance, leaving each of the motors directly connected with the full line pressure, giving the highest speed.

In practice there are several other intermediate steps

on the controller, the resistance generally being divided into two or more sections, but the principle is the same. The motors are reversed by a reversing switch, which simply changes their armature connections, end for end, where they enter the controller.

In addition, a fuse is also included in the circuit of each car and a lightning arrester, which will be described in a subsequent chapter, is also included in the car equipment.

The third-rail system is precisely like the trolley system described above, except that in place of a trolley wire a bonded steel rail is laid on insulators alongside the track, current being taken off by cast iron blocks or shoes which slide upon the rail.

The most elaborate and permanent installations of electric railway are, however, those in which the conducting rails are suspended on heavy insulating blocks in a conduit beneath the street surface, a " plow " or double trolley hung beneath the car being employed to transmit the current to the controllers. The conduit is inclosed in the heavy cast-iron chair pieces of the track structure save at the top, where a slot about three-fourths of an inch wide is left open, between flat plates flush with the street surface.

CHAPTER XVII

POLYPHASE CURRENTS AND MOTORS

Certain great advantages possessed by alternating currents led to their wide introduction for electric lighting, when that art first assumed commercial proportions. At the outset, however, a difficulty was encountered in that electric motors could not be operated by alternating currents. The invention of alternating-current motors, and the system for operating them, was one of the greatest advances ever made in the industrial application of electricity.

If the armature of the alternator, described in Chapter XIV, should have another winding placed upon it so that the parallel bundles of wires forming its coils should lie half-way between those of the winding already described, and if the ends of this winding were brought out to another pair of collector rings, then it is evident that two precisely equal alternating pressures would be generated in the machine at the same time. There would be this important difference between them, however: in the one winding the instants of maximum pressure in either direction, would coincide with the instants of no pressure in the other. In other words, the coils of one winding are passing through the magnetic flux from the pole pieces at the time when those of the other winding are intermediate between the poles and are cutting no lines of force.

If, now, these two windings are connected to circuits of equal resistance, equal alternating currents will flow,

but one will always be behind the other by the interval of time necessary for the armature to turn through the space separating the coils—in this case one-eighth of a revolution. If the armature were turning in the case under consideration, one thousand revolutions per minute, there would be in each circuit 4,000 separate pulses of current each minute, first in one direction, then in the other. This means that there would be 2,000 complete electrical waves or surges out and back per minute in each circuit. One such complete to and fro surging of current is called a cycle, and the number of cycles per second or minute is termed the frequency of the current.

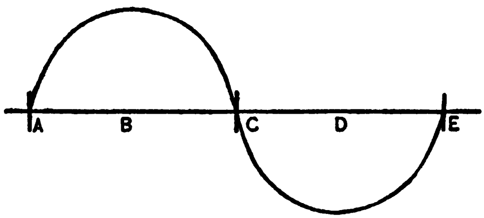

FIG. 32

In commercial practice, frequency ranges from 25 cycles per second in the case of the Niagara power plant to 133 cycles per second in the case of some of the older alternating-current lighting plants.

In Fig. 32 is shown the usual symbolical representation of a complete alternating current wave or cycle. The diagram is simply a convenient method of representing the relations between current flow and time. Time is supposed to be measured from A to E, and the electrical pressure generated by distances above and below the line A E. In the interval between A and B, this pressure increases to a maximum in one direction, while between B and C it falls again to zero at the instant when the di-

rection of pressure is reversed. From C to D it again increases to a maximum in the other direction, when it falls again to zero, marking the end of the cycle and the beginning of the next cycle.

The machine described in Chapter XIV, which has only one armature winding and one pair of collector rings, is called a single-phase alternator. The machine described above having two windings on its armature and two pairs of collector rings, is called a two-phase alternator. Its electrical pressures and hence also the currents in the two circuits it feeds, bear the relation shown in Fig. 33. It will be noticed that these currents are one-quarter of a cycle apart. A cycle comprises the

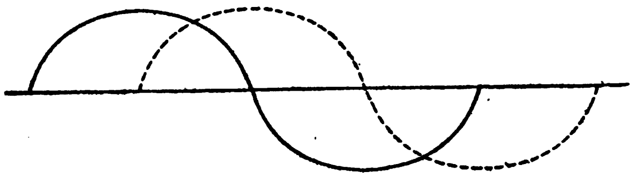

FIG. 33

changes in electrical state of the conducting system during the period of time from a starting time to a recurrence of the conditions at starting time. The word phase is used in speaking of systems of similar alternating currents thus separated from one another by a definite interval, and may be regarded as referring to the separate but like current waves begun within the time of one cycle.

If a machine be constructed with three armature windings, equally spaced around the armature, it will generate three systems of currents having the phase relations shown in Fig. 34. Such a machine is called a three-phase machine. In practice it is found that three col-

lector rings properly connected to the windings are sufficient to lead off such currents along circuits of three wires. Sometimes a fourth ring is added, connected with a neutral point on the winding, and four conductors are used.

The object of such machines, known as polyphase machines, is to provide a variety of current that will operate electric motors of peculiar construction. Of these motors there are two types.

If a polyphase dynamo is connected with another of similar phase relation, it will operate as a motor, pro-

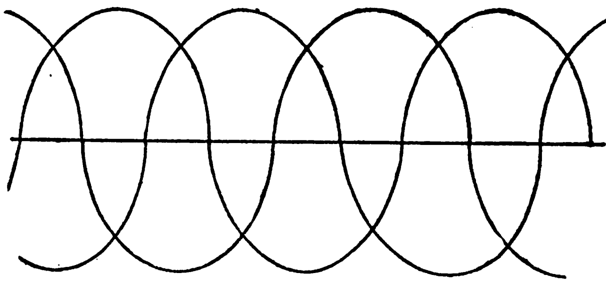

FIG. 34

vided it is first started and driven up to speed before being connected. It has no tendency to start itself, but keeps exactly in step with the generator, and if its field magnetism is properly proportioned, and if it is doing no mechanical work, it generates a back pressure exactly similar in phase and nearly equal in amount to that applied to it. If it is loaded, it lags behind a little in phase, but continues to keep accurate step with the generator. If the latter is driven at a constant speed, the motor will run at a constant speed no matter how heavily it is loaded, up to a certain point. If loaded beyond this point it loses step with the generator and slows down until it

stops. Such a motor is termed a synchronous motor, since it runs in step or synchronously with the generator.

Such motors, on account of their inability to start themselves, have only a limited application. The other type of motor, which depends upon the principle of the

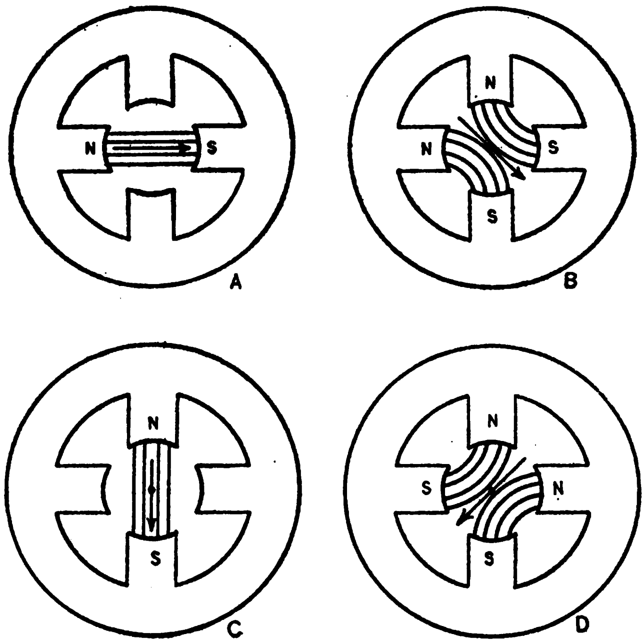

FIG. 35

rotating magnetic field for its operation, is very widely used.

Fig. 35 represents the simple case of a rotating field developed in a four-pole magnetic frame by a two-phase current. Opposite poles are connected to one another and to the same branch of the circuit, so that when mag-

netized, they exhibit opposite polarites. At A the current in the branch supplying the horizontal poles is at a maximum, while that supplying the vertical poles is at the instant of change when no current is flowing. B shows the situation of affairs one-eighth of a cycle later. The magnetism in the horizontal poles has fallen to half its value, while that in the vertical poles is increasing. A quarter cycle has passed in diagram C and now the first branch of the current is at its zero point, while the

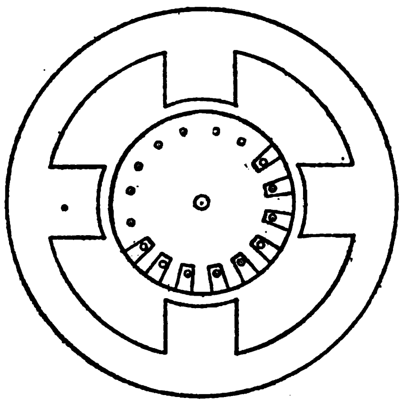

FIG. 36

vertical poles are fully magnetized. Another one-eighth cycle later the polarities are as shown at D. It will be noticed that the direction of the magnetic field as shown by the arrows has constantly shifted and in effect rotated to the right.

If a bar magnet were pivoted at its center, it would always arrange itself parallel to the lines of force, and would consequently rotate with the field; this would be a simple type of two-phase motor. It would be self-starting, but in practice such a bar magnet would soon

become demagnetized, consequently the construction shown in Fig. 36 is used. A cylindrical core of laminated iron, provided with slots similar to the armature core illustrated in Chapter XII, is used, a copper bar being laid in each slot. At each end of the core all these bars are firmly soldered to a copper ring, so that any pair of them, together with the rings, forms a closed electrical circuit. The action of the constantly changing magnetism of the poles, the lines of which cut these conductors, is to induce currents in them. These currents bear such a relation to the magnetism of the pole pieces as to cause the entire central structure to rotate exactly as the armature of a direct-current motor rotates.

The stationary part or field is called the "stator"; the rotating part or armature is called the "rotor." The whole machine is known as an induction motor, since the currents in the rotating element are all induced and not fed directly from the line wires.

The induction motor has many and peculiar advantages. Since it has no commutator, collector rings or brushes, it develops absolutely no sparks in running, and hence can be used in dangerous coal mines or even in powder factories and magazines, as at the government arsenal at Indian Head. It will start itself under any load that it can drive continuously. When running unloaded, the rotor turns nearly in step with the rotating field. As the load is increased it slows down, generally only a few per cent. If the maximum load is exceeded, it simply stops. For the same output it is a little heavier and a little more expensive than a direct-current motor, but not enough so as to affect its commercial usefulness. More than 3,000,000 horse power of induction motors are in use in the United States alone.

CHAPTER XVIII

ELECTRICAL POWER TRANSMISSION

Power can be transmitted conveniently by direct-current dynamos, lines and motors for short distances. Nothing excels in simplicity, convenience and cheapness a system of power transmission, or distribution, using direct-current apparatus, when the conditions are such that it can be used. These conditions are, in brief, relatively short distances of transmission and relatively small powers transmitted.

Commutators will not work reliably at pressures greater than about 700 volts. This sets a limit to the voltage of direct-current systems, which seriously interferes with long-distance power transmission by them. The reason is very simple: The *power* of an electric current depends upon the product of its volume (amperes) and the pressure (voltage) under which it acts. The resistance of a line of wire or cable depends upon its length and the diameter, or, what is the same thing, the weight per lineal unit of the wire. The power *lost* in transmission is measured by the product of the resistance of the line and the square of the current; double the current and the loss is four times as much; treble the current and it is nine times as much. Hence the first essential in long-distance transmission lines is to reduce the current as much as possible, which means to use as high a voltage as can be handled. Given the distance and the amount of power to be transmitted then for any assumed voltage, the dimensions and weight of the line can be calculated

for any degree of loss that is decided upon. There is always some loss.

Generally, a loss of ten per cent is allowed, although, if the cost of power production is very low, greater losses may be economically sustained in order to reduce the cost of the line by reducing its weight.

Because of their ability to work at any voltage that can be insulated—in practice up to 60,000 volts—polyphase systems are almost universally employed for power transmission. Where the length of the line is not so great as to indicate the highest voltages, the generators are often made to give directly the desired pressure. For example, the Chambly-Montreal transmission line, 24 miles long, uses two-phase generators, giving 12,000 volts. This is about the limit of safe voltage that can be directly generated, as at higher voltages the problem of insulating the alternator armature becomes almost insuperably difficult. In order therefore to raise the line voltage to the required high pressure, transformers are used.

The transformer is simply the induction coil described in Chapter VIII. To handle the great powers employed in transmission stations, the transformers are frequently made of enormous size, some being in use, capable of transmitting 3,000 horse-power. Their construction is of the utmost simplicity. Upon a core of sheet iron plates, so arranged as to form a closed magnetic circuit, are placed two coils of wire having different numbers of turns. If an alternating current is supplied to one of these, called the primary, an alternating current of the same frequency may be drawn from the other, called the secondary. The voltage of this current bears the same relation to that of the current in the primary as

the number of turns in the two coils bear to one another. Where no very high voltages are encountered, the transformer is encased in a metal covering simply to keep out dirt and moisture. Where voltages over 2,000 or 3,000 volts are to be handled, the core and its coils are placed in a tank of sheet iron filled with heavy petroleum oil. This oil is a better insulator than air. In very large transformers, coils of pipes through which cold water is circulated by a pump are also placed in the tank of oil, since great quantities of heat are liberated by the heavy currents in overcoming the resistance of the transformer windings. Where raising or " step-up " transformers are used the alternators are generally wound for a conveniently low and safe voltage.

A transmission line almost invariably consists of three wires. Since three-phase currents require the least weight of conductor metal for their transmission, the metal aluminum is very largely employed as a conductor in such lines, stranded cables, composed of seven or more wires twisted together, being generally used. This metal is not so good as copper, and larger cables have to be used, but on account of its great lightness, the weight is not so great as when copper is used, thus reducing the strain on poles and insulators. Aluminum is also somewhat cheaper than copper.

Transmission lines for high voltages are usually supported upon very large porcelain insulators, resembling in shape and size a derby hat. The wire is supported in a groove on the top of the insulator, the lower part of which is deeply flanged so that a film of rain water cannot easily form upon it. Wooden poles are generally used, and very often a line of barbed fence wire is run along the top of the poles and connected at frequent

intervals to plates buried in the ground as a protection against lightning.

At the receiving end of a transmission line transformers are generally installed to reduce the high line voltage to a convenient pressure for distribution to motors, etc. Induction motors of large size will work satisfactorily upon very high voltages, since they have no commutators or contacts of any kind. In general, about 2,000 volts is the pressure adopted for distributing current from the receiving stations, this pressure having become standardized for many purposes, notably for electric lighting.

It is often desired to utilize the transmitted currents for operating street railways or for other purposes requiring direct current. This can be done by driving a direct-current dynamo from an induction or synchronous motor. In practice it is more usual to employ a machine called a rotary converter, which will convert polyphase into direct current, or vice versa. This machine consists of a direct-current dynamo, which has as an addition to its commutator three collector rings (in case three-phase currents are used) connected with three points in the winding equally spaced around the armature. Such a machine supplied with alternating current will run as a synchronous motor and at the same time deliver direct current from its commutator brushes. If fed with direct current, it will run as a motor and deliver three-phase current from its collector rings.

The efficiency of electrical power transmission is remarkably high. Large alternators deliver as electrical energy 97 per cent of the power supplied them. Transformers at full load waste less than three per cent. Transmission lines lose anywhere from two or three to

fifteen or twenty per cent, according to their design. Rotary converters will convert as high as 98 per cent of the energy supplied to them.

The longest transmission line in the world is that from Colgate to Oakland, Cal.—two hundred and twelve miles long and operated at 60,000 volts. One of the most famous lines is that from Niagara Falls to Buffalo, which transmits about 20,000 horse-power at 22,000 volts. Part of this line is laid underground.

The greatest value of transmission lines lies in their ability to make the power of waterfalls, often most inconveniently situated, available at a distance, in places where it can be used to the highest advantage.

CHAPTER XIX

THE INCANDESCENT LAMP

The incandescent lamp furnishes the most familiar example of a conductor heated by the passage of an electric current. It consists of a fine filament or wire of carbon, sealed in a glass bulb, from which the air is exhausted, and provided with terminals to make proper contact with the circuit feeding the lamp. When current passes through the carbon, which is a poor conductor, heat is generated in it. The length, diameter and resistance of the filament are proportioned so that when a definite pressure is applied to the lamp, 110 volts, for example, enough current will pass through the filament to heat it white hot. If too high a voltage is used the filament becomes too hot and vaporizes. If too low a voltage is used the filament does not become hot enough and gives a reddish yellow and dim light.

The method of making incandescent lamps is very interesting. The bulbs come from the glass-blowers in bunches of six or eight, united by tubular stems running out from the tip or large end of the bulb. The subsequent sealing of these tubes and removal of the bulb leaves the small tip or point of glass on the rounded end of the bulb. The other ends of the bulbs are open and are about three-quarters of an inch in diameter.

The glass stem projecting into the lamp from its base or connecting end is really a sort of stopper, which is sealed into place. The filament and leading-in wires are

mounted upon this piece before it is placed in the bulb. Through the hollow stem two copper wires are run to a point as near the end of the stem as possible. Here they are soldered to two fine platinum wires, which are sealed through the glass and to which the filament is attached. The reason for using platinum, one of the most expensive of metals, is that it alone will make a tight joint when sealed into glass. All other metals in expanding and contracting under varying degrees of heat break away from the glass and, in the exhausted bulb of an incandescent lamp, would soon form cracks through which air could enter and spoil the lamp.

To the terminals of the platinum wires the filament is attached by a cement that, upon heating, covers the juncture of the metal and the filament with a coating of conducting carbon. In some cases, where the filament is long or the lamp is to be used where there is much vibration, the middle of the filament is anchored, that is, cemented to a wire sealed in the walls of the bulb so as to prevent its swinging and striking the glass.

The filament itself is a carbonized thread of some organic material. Formerly silk, paper, bamboo fiber, etc., were much used, but now nearly all filaments are made of pure cellulose. This is the material of which cotton and wood-pulp fibers are composed. By suitable chemical means it is dissolved into a gummy liquid. This is "squirted" through a glass teat in a fine stream which hardens into a fine round thread, resembling a small catgut banjo string. These threads are wound upon an iron former, which gives them the shape desired for the filament, and the former, with the threads in place, is then packed in an airtight iron box, surrounded by powdered charcoal, and heated red hot for several

days in a furnace. In this way the threads are converted into pure carbon filaments.

The filament being mounted on its support, the glass base is sealed into a bulb. When the bunch of bulbs is thus equipped with filaments it is connected by its stem (from which the branch tubes lead off to each bulb) to an air pump and the air is exhausted. Enough current to heat the filaments to a dull red heat is then sent through them to drive out any lingering particles of air from the pores of the carbon. When this process is completed, the lamps are "flashed."

Flashing is the operation that makes the filaments perfectly uniform. Up to now they may vary slightly in size or in electrical resistance from point to point. When heated by the current some parts are noticeably hotter than others. To remedy this, a small amount of the vapor of some hydrocarbon, such as gasoline, is allowed to enter the exhausted bulbs. Now, upon heating the filaments again this vapor is decomposed by the hot carbon and deposits carbon upon the filament—more at the hot points than elsewhere. In a few minutes this deposit builds up the thin places so that the filament glows uniformly.

After flashing the pumps are again set to work and the bulbs exhausted as thoroughly as possible. The object of this is to prevent the burning of the carbon filament. If the air were not removed from the bulb the filament would take fire and burn as soon as it was heated. When thoroughly exhausted the bulbs are "sealed off." A blow-pipe flame is played upon the stem connecting each bulb to the bunch, softening the glass so that the little tubular stem collapses to form the pointed tip on the head of the bulb.

All that now remains to finish the lamp is to cement on its brass base with plaster-of-paris and connect the leading-out wires to the two parts of the base. The base almost universally in use consists of a screw of four or five threads forming the external part and a central plug. These, insulated from each other by the plaster-of-paris, are connected respectively to the two leading-out wires by a drop of solder and the lamp is finished.

The average sixteen-candle power incandescent lamp consumes from forty-eight to fifty-six watts. Such a lamp, made for 110 volts (a standard voltage), permits a current of from 0.436 to 0.50 amperes to pass when that pressure is applied to it.

Incandescent lamps are made in commercial sizes of from one-half to one hundred candle-power, the size most in use in the United States being sixteen candle-power; in Europe the eight candle-power lamp is most largely used. They are made for all voltages up to about 250 volts. For a long time the standard voltages ranged from 100 to 125 volts, but lately many installations using lamps of 220 volts and over have been made.

In almost all cases incandescent lighting is done on the constant-voltage system. The two sides of the circuit are maintained at a constant difference of pressure by the dynamo or other source of current and the lamps are bridged across—connected from one side of the circuit to the other. Small lamps, such as are used in electric signs and decorations, are generally made for low voltages, such as 15 volts, and for commercial circuits are connected in series in groups, thus eight 15-volt lamps in series on a 120-volt circuit.

Notwithstanding the high mechanical perfection of the incandescent lamp, it is by no means efficient. The

electrical energy absorbed in it is changed into heat and radiated away from the filament partly as visible light, but much the largest part as heat. Only about five per cent, or less, of the energy consumed is returned as light; the remainder is evident only as heat. To remedy this difficulty many plans have been proposed. The carbon-filament lamp, described above, can be fed with a higher voltage, thus greatly increasing the whiteness and brilliance of its light and increasing the effective light per watt of power consumed, but the carbon cannot long withstand the enormous temperature produced in it and the life of the lamp is reduced below commercial limits. The search to discover a substitute for carbon has been protracted, but only one substance has been found, so far, which gives promise of commercial availability.

Dr. Walther Nernst recently discovered that many of the refractory oxides, such as magnesia and zirconia, which are almost perfect insulators when cold, become poor conductors when glowing hot. The lamp bearing his name is made of a rod, or rods, of such an oxide, together with some means for heating it. For 110 volts the rod is about the diameter of hairpin wire and about three-quarters of an inch long. Connected with a circuit no current passes until it is heated. If heated red hot, by a match, for example, current begins to flow and soon heats the rod or "glower" to blazing incandescence. As constructed, such lamps are provided with a coil of platinum wire placed very close to the glower. When current is turned on, this wire is heated white hot, and, in turn, heats the glower. As soon as the latter begins to conduct an electromagnet connected in circuit with it becomes active and opens a switch which cuts off

current from the platinum heating coil. Nernst lamps give a beautiful white light and require only about one-half as much electrical energy for a given candle-power as incandescent lamps.

The methods employed in distributing current for incandescent lighting, in maintaining uniform voltage over an extended network of conductors, in securing certainty of operation and freedom from accident, form one of the most important branches of electrical engineering. Even the briefest description of them would require a larger space than this little volume affords.

CHAPTER XX

THE ARC LAMP

When a strong current is flowing from one to another of two pieces of hard carbon in contact, if they are separated a short distance, an intensely brilliant blaze of light fills the gap between them, and the current continues to flow, showing that the space is bridged by some conducting substance. Close examination shows the light to come from three points, the parts of the two carbons closest to one another and a little flame which plays between them. If the carbons take the form of rods and are horizontal, this flame is bowed upward. For this reason the whole phenomenon was named by its discoverer, Sir Humphry Davy, the electric arc.

In the modern arc lamp, which utilizes the principles of the electric arc, the carbons are in the form of round rods, generally one-half inch in diameter, and are placed vertically one above the other. The necessary mechanism of an arc lamp consists of the two carbons, means for separating them to establish the light—to "strike the arc," and means for feeding one or both of them into the arc as they burn away.

The older type of arc lamps is intended for direct current, and almost always to be operated on a circuit in which a constant volume of current-flow is maintained, generally either 6.6 or 10 amperes. The lower carbon is solidly fastened to the frame of the lamp; the upper one is attached to the end of a smooth rod of metal arranged to slide vertically through bearings. In a casing

at the top of the lamp frame is the mechanism for striking the arc and feeding in the upper carbon from time to time.

The two carbons are not consumed at equal rates when direct current is used. That from which the current passes is noticeably hotter and gives off much more light from its glowing tip than that to which the current passes. It also wastes away about twice as fast. For

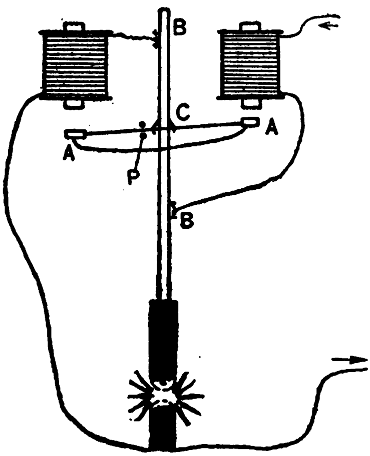

FIG. 37

this reason the anode or "positive" carbon is always made the upper in such arc lamps and is fed downward. As it is the hottest, the greater part of the light of the lamp is thrown downward, which is desirable, while the relatively less rapid combustion of the fixed carbon causes the arc to change its place with reference to the globes, reflectors, etc., used with it slowly.

In Fig. 37 is shown a diagram of the usual mechanism for starting and feeding a street lamp on a constant di-

rect-current circuit. It consists of two electromagnets and a clutch or device for gripping the rod carrying the upper carbon. The lever, A A, carries the clutch, C, and is pivoted at P. The clutch is so made that when the lever is horizontal the rod can slide through it. When the lever is pulled up by the right-hand electromagnet the clutch grips the rod and moves it up.

This right-hand electromagnet is of coarse wire and is connected as shown so that the current from the line passes through it and to the arc through the brush, B, resting on the rod. When current is turned on this electromagnet immediately acts, pulling up the clutch and separating the carbons so as to establish the arc.

The other electromagnet is of fine wire, of high resistance, and is connected to the rod and to the lower carbon as shown. As soon as the arc is established a part of the line current flows through this electromagnet, and as the arc lengthens, from the burning away of the carbon points, thus increasing its resistance, there is an increasing difference in electrical pressure between the two carbons and an increasing current through the fine wire winding. This presently reaches such a point that the attraction of the coarse wire electromagnet is balanced, the lever, A A, becomes horizontal, and the rod slides downward (by its own weight) through the clutch feeding in the upper carbon. This shortens the arc, decreases its resistance, cuts down the flow of current in the fine wire electromagnet and hence its pull, and the lever goes back, the clutch again holding the rod. In this way the carbon is fed in bit by bit until all is consumed.

The lamp described above is typical of the so-called "open arc" street lamp, of which many thousands are

in use for street lighting. A great improvement in arc lighting is the inclosed arc lamp. In this the arc burns in an airtight transparent vase or globe of small dimensions, which, by excluding the outer air greatly lessens the burning away of the carbons and lengthens their life. An ordinary twelve-inch carbon in an open arc lamp is consumed in eight hours; in an inclosed arc lamp, it will burn 150 hours.

Inclosed arc lamps are made for both alternating and direct-current circuits, and either for constant potential or constant current supply. The differences between the various types is confined to their mechanical arrangements and to the connection of the coils used in starting and feeding.

In lamps used for certain purposes, where the arc must be kept in the same place (and not travel downward with the burning away of the lower carbon) both carbons are fed in, one twice as fast as the other. Such lamps are used in searchlights. These consist of a metal case having a reflector at the back and a lens in front, the arc being placed at the focus of both. This arrangement concentrates the light of the arc in a powerful parallel beam, which may be moved about at will by moving the whole apparatus. In searchlights the arc is often fed by hand.

The arc light is more efficient than the incandescent light; that is, it gives more candle-power per unit of power absorbed. The ordinary commercial ratings "2,000 candle-power" and "1,200 candle-power" are absolutely misleading. They were guesses at the luminous power of open-arc lamps, made in the days before the art of photometry, or light measurement, was practised. Commercially, they mean arcs of 10 and 6.6 am-

peres respectively, with about forty-five volts difference in pressure at the terminals of the lamp. According to the quality of the carbons (which exerts a very large influence) and the direction from which measurements are made the actual candle-power of a street arc may vary anywhere from 600 or 700 down to 250.

Carbons for arc lamps are made of petroleum coke, ground as fine as possible and mixed into a stiff paste with tar. This mixture is squeezed by hydraulic pressure through dies to form the round rods, which are then baked in an intense heat for several days. Carbons are sometimes copper-plated to improve their conducting qualities, and are often made with a core of different composition to improve their burning qualities. For inclosed arc lamps they must be very free from impurities, which darken the inclosing globes.

CHAPTER XXI

ELECTROCHEMISTRY—STORAGE BATTERIES

While the heating and magnetic effects of electric currents, as exhibited in lighting and motive power, are the basis of its most important engineering applications, a new industry of great magnitude is growing out of the use of electricity to effect chemical decompositions, either by cold processes or in connection with the enormous degrees of heat obtainable in the electric furnace.

The larger part of the refined copper sold in the American market is reduced from the matte, or impure metal, by electrical action. The method used is that described on page 16, where two electrodes of the same metal are immersed in a bath of a solution of that metal's salts. In electrolytic copper refining the matte, which carries a large percentage of impurities, is cast into slabs or ingots. These are suspended in wooden tanks containing a solution of copper sulphate. In the same tanks are also suspended thin sheets of pure copper. Current is sent through the bath from the anode slabs of matte to the cathode copper plates, causing the matte to dissolve and its copper to be deposited in metallic form on the plates. As the slabs of matte are dissolved the impurities fall to the bottom of the tank as a slime or mud, while the plates grow from additions of copper to become heavy masses of that metal. The slime contains, in many cases, in addition to sand and iron and other metals, enough silver to pay all the expenses of the process.

Thousands of tons of copper are refined by this process monthly.

Caustic soda and bleaching powder are made in enormous quantities by electrical processes from common salt. One of these processes is as follows:

A slate tank is divided by a slate partition into two parts, the partition reaching nearly but not quite to the flat bottom of the tank. A quantity of mercury, sufficient to reach a little above the bottom of the partition, is placed on the floor of the tank, and one compartment is filled with water while the other is filled with strong brine. In the latter compartment is suspended a block or plate of carbon. Current is sent from this carbon block to the mercury, decomposing the salt in solution into chlorine gas and metallic sodium. The gas bubbles up through the brine and is collected in a hood and piped to chambers containing trays of quicklime. This absorbs the gas, becoming the ordinary bleaching powder or "chloride of lime" of commerce. The sodium forming at the surface of the mercury is immediately dissolved by the liquid metal. Sodium has a powerful affinity for water, and as the mercury becomes saturated with it, the water in the second compartment of the tank continually dissolves it out of the mercury, forming sodium hydroxide or caustic soda. This liquor is evaporated, leaving the solid caustic, often sold in small packages as "concentrated lye."

The metal aluminum, when made by chemical processes exclusively, was so expensive as to have practically no commercial use. It is now made electrolytically, and is cheaper than any other metal except iron, zinc and lead. One process for making it is as follows:

In a carbon-lined tank, or crucible, the mineral cryo-

lite (aluminum fluoride) is melted. This melted cryolite will dissolve aluminum hydroxide, which exists in nature as a clayey mineral called bauxite. Vast quantities of bauxite are found in Arkansas. In the bath of melted cryolite and bauxite is a carbon electrode. Current is caused to flow from this to the carbon walls of the crucible. The cryolite is decomposed, forming metallic aluminum, which gathers in a melted condition at the bottom of the bath, and fluorine. The latter immediately combines with the bauxite present to form more aluminum fluoride or cryolite. In this way the process is continuous. After the first heating, to melt the bath, its own resistance causes enough heat to be engendered in it by the passing current to keep it melted. The aluminum is drawn off from time to time from a tap hole and cast into molds. Bauxite is added to the bath as it is consumed, and the process continues until the accumulation of impurities and slag becomes too great and the crucible is cooled off and cleaned.

The electric furnace is of two kinds, one depending upon the heat generated by heavy arcs struck between carbon electrodes, and the other upon the heat generated by a current passing through a resisting mass, generally the ores or materials to be treated.

The arc furnace is used in making calcium carbide, a curious substance, which generates acetylene gas when brought in contact with water. At Niagara, this carbide is made in carbon-lined iron boxes, which are placed in brick vaults. Through the roof of the vault a carbon rod, the size of a stovepipe, is lowered by a block and tackle until it strikes the carbon floor of the box. A powerful alternating current is sent through the contact and the carbon rod lifted a little so as to strike an arc.

Through chutes leading into the box a mixture of powdered coke and quicklime is shoveled. In the fervent heat of the arc these melt together, forming calcium carbide—a purplish black solid.

Carborundum, a jewel-like substance, almost as hard as the diamond, and used in place of emery and the like as an abrasive, is made in the second class of furnace. A brick rectangle about fifteen feet long and five feet wide and high is laid, and in this is built up a core of ground coke running from end to end, and surrounded by a mixture of ground coke, sand and sawdust. The latter is put in so that in burning out it leaves the mass porous and makes the escape of resulting gases easier. At the ends of the coke core massive carbon plates make connection with it. An alternating current of several thousand amperes is sent through this core, and in a few hours raises it to a temperature higher than that attainable in any combustion furnace. In this tremendous heat the sand and coke unite to form a crystalline solid showing beautiful iridescent colors. These crystals are crushed and molded into wheels, etc., for use in grinding and cutting.

One of the most valuable products of electrochemical study is the storage battery. This is an electric battery, which, when it has exhausted itself, may have its powers renewed by sending a current through it in the opposite direction to that it gives while working as a battery. It thus becomes, in effect, an appliance for storing electrical energy, since it can be charged by the current and will then restore a large proportion of the electrical energy used in charging it.

The ordinary storage battery is made of plates of lead and the oxides of lead, in a cell containing dilute sul-

phuric acid. In its discharged or neutral condition both plates may be considered to consist of lead oxide. When the current passes from plate to plate, in charging, this oxide becomes spongy metallic lead at one plate, and lead peroxide, a brick-brown material, at the other. These two substances, lead and lead peroxide, in sulphuric acid constitute a battery of great power and constancy. When current is withdrawn from it the peroxide loses part of its oxygen, and becomes lead oxide again, while the spongy lead again becomes oxidized. The plates are thus restored to their original condition, ready for another charge and discharge.

A new type of storage battery, due to Mr. Edison, uses no lead and hence gains considerably in lightness. Its plates are made of nickel steel containing pockets, in which are placed the active materials. In one this consists of a mixture of graphite and nickel oxide; in the other, of graphite and iron oxide. The fluid employed is a solution of caustic potash. The chemistry of this cell is not very well understood, but its storage capacity per unit of weight is very high.

Storage batteries are made in many sizes and of different designs for different purposes. Each cell (of the lead type) gives a pressure a little in excess of two volts, which diminishes as the charge is withdrawn. In general, each cell contains a large number of plates, half of which are connected to one terminal, and the other half to the other, so that, electrically speaking, there are only two plates in a cell. In some large railway and electric-light stations, storage batteries of great size are used to store current during those hours of the day when the demand for power is small and to assist the generators in supplying the lines during hours of heavy load. Such

storage batteries are also very useful in maintaining the voltage of the line constant, acting much as a flywheel on an engine does to absorb the smaller fluctuations of voltage due to a great number of causes.

The electric automobile is furnished with a controller and motors very similar to those used on a trolley car, though, of course, smaller. It carries a storage battery of from twenty to fifty cells, the size and weight of the cells determining the amount of energy that can be stored, and hence the distance the carriage can run without recharging.

CHAPTER XXII

WIRELESS TELEGRAPHY

At the time this chapter is written there is still some uncertainty as to the explanation of the phenomena observed in wireless telegraphy. For this reason the explanation given below must be regarded as tentative merely, since the future may produce some more satisfactory theory of the subject.

The illustration, Fig. 38, shows in diagram, a Mar-

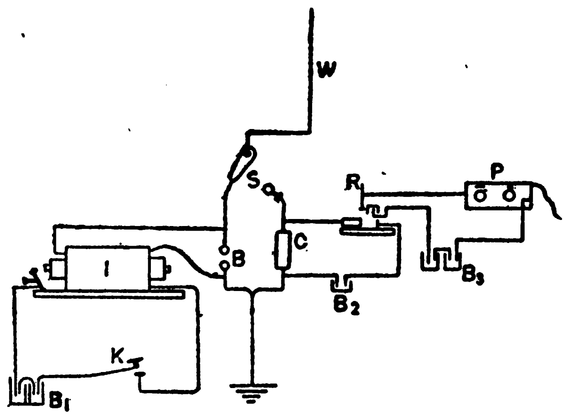

FIG. 38

coni station for sending and receiving wireless messages.

W is a vertical wire, supported by a pole or mast as high as possible. This wire is very carefully insulated. Its lower end terminates in the switch, S, which connects it at will with either the sending apparatus, shown on the left, or the receiving apparatus, shown on the right of the diagram.

The sending apparatus consists of a battery, B_1, a key, K, a powerful induction coil, I, and a pair of metal knobs or balls, B. One of these balls is connected to the earth, E, by a wire and a plate buried in the ground. The other is connected to the vertical wire, W. The distance between the balls can be regulated.

When the key is depressed the circuit is closed from the battery through the primary of the induction coil and the interrupter (see Chapter VIII) is thrown into rapid vibration. Alternating pressures of great magnitude are generated in the secondary of the coil, high enough to break through the air-gap between the balls at B as a shower of bright sparks. The vertical wire, W, is thus charged and discharged, every stroke of the interrupter charging it with a high electrical pressure, which is relieved by the spark making a momentary path through which the charge rushes to earth.

Brief as is the duration of the spark, it is long enough for a curious action to take place. Instead of the charge in the vertical wire simply flowing away to the earth through the path offered by the spark, it suddenly rushes to earth, and, since electric currents seem to have a species of inertia, more charge rushes out of the wire than was put in it. A surge in the other direction then takes place, and then one to earth. In other words the wire recovers its electrical equilibrium much as a bent spring becomes straight when released—after a series of decreasing oscillations.

Thus every spark represents a series of almost infinitely rapid electrical oscillations, currents surging up and down the wire and across the spark gap for a brief fraction of time at the rate of several million per second. The sparks are repeated at intervals of perhaps one-

twentieth or one-thirtieth of a second, according to the speed of the interrupter.

Now, oscillations of this character have the power to set up electrical vibrations or waves that traverse the air as does a light wave. It has been thought that these waves, called Hertz waves, since they were discovered by Dr. Heinrich Hertz, were the agency that transmitted the electrical disturbance from one station to the other; but recent work with wireless telegraphy has not borne out this idea. It seems more likely that what happens is like this:

The currents rushing into and out of the earth at E tend to charge and discharge the earth itself, or that portion of it immediately concerned.

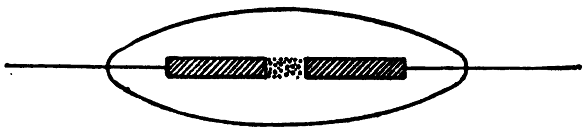

FIG. 39

The disturbance set up by the rapid oscillations travels in radiating waves along the surface of the planet in all directions from the point E, just as ripples spread out in all directions from the point where a stone is dropped into still water. It is believed that these electrical ripples are what affect the apparatus at the receiving end.

Turning now to the receiving instruments, we have only to imagine the switch, S, in Fig. 38, thrown the other way to convert the station into a receiving station.

Connected by one terminal to the vertical wire, W, and by the other to the earth, is a "coherer," C. This instrument is simply a small glass tube containing two

silver plugs (see Fig. 39) between which loosely rests a minute pinch of metallic filings. The tube is sealed, and to prevent the oxidation of the filings is exhausted of air. The illustration shows it rather larger than actual size. The electrical resistance of these filings loosely lying together is very high, so high that the small battery, B_2, cannot force enough current through it to affect the telegraph relay, R (see page 23), with which it and the coherer are connected in circuit. A curious property of such filings is, however, that electrical waves or rapid oscillations of voltage seem to cause the filings suddenly to stick together or "cohere," causing an immediate decrease in their resistance.

A third battery, B_3, is connected with the relay, R, and a tape-printing telegraph instrument, P. It also operates a "buzzer" (see page 29), the hammer of which very gently strikes the coherer so as to jar the filings loose from one another after they have cohered. This is not shown in the illustration.

If, at the sending station, the key is depressed for long or short intervals, corresponding trains of successive groups of electrical ripples are started out from the ground connection. As these expand, they encounter the ground wire of the receiving station. They tend to ascend the vertical wire, and, in so doing, influence the coherer, causing its resistance to drop. The battery, B_2, can then send its current through the relay, which, in turn, works the tape-printing machine through the battery, B_3. So long as the key is held down and the electric waves influence the coherer, so long will the point of the tape printer mark the moving paper tape. The buzzer is striking the coherer, but without effect as long as successive waves are keeping it cohered. When the

key is opened the waves cease to flow away from the sending station, and the next tap of the buzzer causes the coherer instantly to increase its resistance, opening the relay, R, and the printing machine, P. In this way long and short signals on the key, K, are received as long and short marks on the tape at the distant station.

There has been much talk of "tuned" or "syntonic" systems of wireless telegraphy, by which is meant the construction of receiving apparatus that would be responsive only to one frequency of electrical oscillations, and hence would receive only signals designated for it. While much has been promised, little seems to have been accomplished in this direction, and certain inherent difficulties in the very nature of electrical oscillations seem to stand in the way.

There are various other systems of wireless telegraphy. In all of them the sending apparatus is practically identical. Most of them employ the coherer or similar wave-responsive devices. At the time of writing, the longest distance over which wireless signals have been sent is about 1,500 nautical miles.

CHAPTER XXIII

RADIATION—X-RAYS

Radiant energy, or energy which has the property of traversing space in straight lines, is known under many names. Its most familiar aspect is light, but its various forms merge into one another with perfect continuity and differ only in one respect—the frequency of the vibrations that compose them.

In some way, not yet fully understood, the very rapid vibrations of atoms and molecules, the ultimate particles of matter, are taken up by the ether. This ether is a material of which our senses give us no sign, but whose properties are as well known as are those of iron. It is believed to fill all space, including the intervals between the constituent particles of matter. It is perfectly elastic and it transmits vibrations impressed upon it at the enormous speed of 183,300 miles a second. This tenuous material is the bridge by which radiant energy traverses space.

If the ether is set slowly swinging, say several million times a second, the radiations that traverse it are the Hertz waves spoken of in the last chapter. If the molecules of a body are jostled and set swinging by heat they impress a swifter vibration upon the ether, which we know as radiant heat. We feel the impact of these undulations upon us when we stand by a hot stove. If the heat grows more intense, the swinging of the molecules faster, we begin to notice a dull red light. This means that the molecules are swinging about 400 million mill-

ion times a second. A still greater degree of heat, such as is noticed in the filament of an incandescent lamp, causes the molecules to sway the ether more than twice as fast.

Now, the eye is an instrument that perceives ether undulations only when they range between about 395 and about 760 million million a second—less than a single octave in the tremendous gamut of possible vibrations. For this particular range of vibrations we know that substances like glass are transparent, while other substances like hard rubber are opaque. These properties do not, however, extend through the whole range of radiation by any means. For example, glass is quite opaque to radiations both of higher and lower frequency than those that happen to be visible. Hard rubber is very transparent to lower and higher frequencies. Lenses and prisms are made of pitch for the study of Hertz radiations, so transparent is this substance to them.

The radiation of the highest known frequency of vibration, a frequency estimated (though not measured) as over 3,000 million million per second, is called the X-ray. To it, wood, hard rubber and flesh are transparent, and on this account it has been found of service, permitting shadows of the bones of a living person to be made without inconvenience. These shadows are of inestimable value in surgical diagnosis.

X-rays are generated by the impact of electrically charged molecules or free particles of a gas, moving at high velocity, against a solid substance. The usual apparatus for producing them is the glass bulb or tube, illustrated in Fig. 40. C is a concave mirror or disk of aluminum. A is a small piece of sheet platinum, set at an angle as shown, and B is a leading-in wire of platinum

sealed through the wall of the tube. A similar wire connects with C. A voltage of about 100,000 volts is applied to B and C, either from the terminals of an induction coil or from a " static " electric machine. The electrical pressure must be such that current will flow from B toward C.

The glass bulb containing A, B and C is exhausted as completely as possible so that not more than one-millionth of the original air remains in it. Under these circumstances the remaining molecules of air are so far

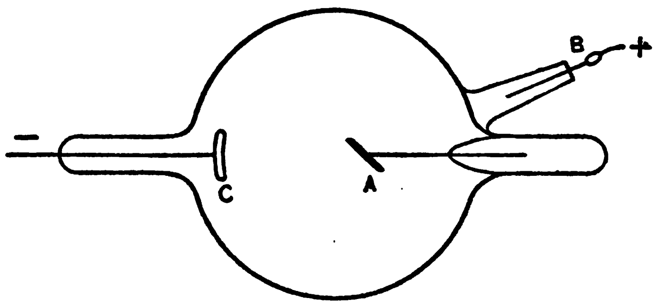

Fig. 40

apart they can move several inches without colliding with one another.

It was discovered about twenty years ago by Sir William Crookes that in a nearly perfect vacuum the residual particles of gas were repelled in straight lines perpendicularly away from the surface of the cathode in a tube such as is shown in the illustration. If the cathode is made concave so as to concentrate the particles repelled away from its surface toward one point, and a piece of metal be held at the focus of these streaming particles, they will heat it red hot.

Dr. Wilhelm Roentgen discovered that they would do

more than this. They would produce at the point of their impact with the platinum target, A, vibrations of almost incredible frequency, from which streamed a radiation of such mysterious properties that, being in doubt of its nature, he christened it the X-ray. It is known now to be high-pitched light, so to speak.

The whole range of radiation, from Hertz waves to X-rays, is, in fact, an electrical phenomenon. It would be impossible here to go into the array of reasons that long ago convinced Maxwell that light consists of waves of electromagnetic energy, but from this conviction he predicted the existence of the electrical waves later discovered by Hertz. He might even have gone a step further and foreseen the possibility of the X-rays.

The question of the nature of electricity seems in a fair way to be answered. Recent experimental work of Professor J. J. Thomson has shown the apparently separate existence of masses of matter smaller than the atoms of the chemist, each carrying a definite electrical charge, and has dimly foreshadowed a new material concept of the nature of electricity itself.